DOT HS-805-184

IFICATION OF APPROACHES FOR THE CONTROL :ALTH, ENVIRONMENTAL, AND SAFETY HAZARDS SOCIATED WITH AIR BAG USE AND DISPOSAL

Arthur D. Little, Inc.
Acorn Park, Cambridge, Massachusettes

Contract No. DOT HS-8-01995
Contract Amt. $50,406

August 1979
FINAL REPORT

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Prepared For
U.S. DEPARTMENT OF TRANSPORTATION
National Highway Traffic Safety Administration
Washington, D.C. 20590

Technical Report Documentation Page

1. Report No. DOT-HS-805-184	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Identification of Approaches for the Control of Health, Environmental, and Safety Hazards Associated with Air Bag Use and Disposal		5. Report Date August 1979
		6. Performing Organization Code
7. Author(s)		8. Performing Organization Report No.
9. Performing Organization Name and Address Arthur D. Little, Inc. Acorn Park, Cambridge, Massahusetts		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DOT-HS-8-01995
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration Department of Transportation 400 Seventh Street, S.W. Washington, D.C. 20590		13. Type of Report and Period Covered Final Report Aug. 1978 to April 1979
		14. Sponsoring Agency Code
15. Supplementary Notes CTM- A.C. Malliaris NRM-12		

16. Abstract

This program was undertaken by examining previous work conducted by various parties to assess the magnitude of any potential risks resulting from the use of air bag restraint systems. Specific potential hazards associated with the safe handling and disposal of inflator modules were indentified and individual amelioration techniques were examined for various stages of vehicle life cycle. A countermeasure analyis indicated that perhaps the most effective method for providing the safe handling of retired cars with un-deployed air bags requires that they be safely deployed early in the automobile recycling process.

17. Key Words Safe disposal of air bag restraints	18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield,VA 22161		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 130	22. Price

Form DOT F 1700.7 (8-72)

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METRIC CONVERSION FACTORS

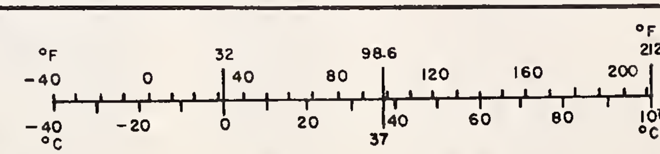
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

INTRODUCTION

U.S. automobile manufacturers are required, under the provisions of Federal Motor Vehicle Safety Standard (FMVSS) 208, to provide automatic occupant crash protection in their new 1982 large size passenger vehicles. Smaller cars must provide such protection in succeeding years. Current trends within the industry suggest that inflatable restraint systems will be utilized by major automobile manufacturers to provide the required passive restraint for a small percentage of their new automobiles in the early 1980's. Virtually all auto companies that plan to commercialize air bags will use a system employing sodium azide to generate the nitrogen gas to inflate the bags.

Several programs have been sponsored by the automobile companies to evaluate alternative design configurations, and to examine the impacts and potential risks associated with the use of these restraint systems upon people, property and the environment. Recent studies completed for the Motor Vehicle Manufacturers Association (MVMA) by Arthur D. Little, Inc. (ADL) and Battelle Columbus Laboratories (Battelle) and for the Ford Motor Company by Thiokol Chemical Corporation (Thiokol) have suggested that under certain circumstances chemicals used to generate gases may have an effect on people, property and the environment. In general, the results from these studies indicate that the only potential problems associated with the use of air bags would occur during the disposal of cars with nondeployed inflator modules.

APPROACH

The National Highway Traffic Safety Administration (NHTSA) is the principal Federal agency responsible for improving motor vehicle safety on the nation's highways. NHTSA has long been an advocate of automatic restraints for occupant crash protection in automobiles. The agency recognizes that the best way of safely handling and disposing of retired

inflator modules has yet to be determined. The present study was undertaken to provide an initial identification and assessment of the various ways of ensuring that pyrotechnic inflator modules are properly handled during the recycling and disposal of scrap automobiles.

This program was undertaken by examining previous work conducted by individual automobile manufacturers, MVMA, NHTSA, and other parties to assess the magnitude of any potential risks resulting from the use of inflatable restraint systems. Specific potential hazards associated with the safe handling and disposal of inflator modules were identified based upon consideration of potential impacts upon the physical, biological and human environment. Individual amelioration techniques were examined for the various stages of the vehicle life cycle where programs could be implemented to reduce the potential risks associated with particular events. A countermeasure analysis indicated that perhaps the most effective programs for providing the safe handling of retired automobiles with undeployed air bags requires that they be safely deployed early in the automobile recycling process. These deployment activities could be undertaken at the dismantler/recycler and scrapyard facilities, or at designated inspection-deployment centers.

Several alternative programs were examined to assess their effectiveness toward achieving the goal of safe handling and disposal of retired air bag inflator modules. Included among these were:

1. Hardware modifications
2. Hardware modification coupled with either a fee/incentive or penalty/disincentive program to encourage the proper handling of retired motor vehicles such that these must enter the recycling process and do not become abandoned, and
3. A program using centers to inspect, service, and (when a car is to be scrapped) dispose of air bag modules by deployment or removal.

Each option was qualitatively evaluated against specific performance criteria to assess its relative merits. A second level of analysis focused upon the feasibility of modifying inflator hardware to insure their safe handling and disposal.

RESULTS

The results of this study suggest that there are several devices that could be utilized to deploy retired inflator modules by electrical, electromagnetic, chemical or mechanical stimuli. The successful application of a deployment mechanism requires that the current inflator design be modified to insure that the specified external stimulus is sufficient to cause deployment of the retired inflatable restraint system. These changes must not affect the reliability of the system. The alternative design options were evaluated to determine:

- the initial cost for hardware modifications
- the time frame required for implementation
- the impact upon air bag reliability during normal use
- the potential for accidental deployment during servicing or repair of the module
- the ease of operation or utilization of the deployment device
- the requirements for training and protection of deployment personnel
- the provision needed for housing, storing or ensuring security for the deployment device

Upon completion of the hardware assessment, ten modifications were identified that could be incorporated into inflator or air bag system designs to aid in the deployment of the module in a car being scrapped. The modifications are identified according to the signal source or device used to deploy the inflator module. The following is a description of each, ranked according to their attractiveness on the basis of the present research.

1. <u>12-Volt DC Battery</u>. A 12-volt dc battery is used to trigger the air bag through a remote electrical plug or unique configuration that would be built into the automobile equipped with air bags. This would allow recyclers to deploy air bags at the time a car enters the scrappage process, from a remote location, so that workers would not be exposed to any danger from them.

2. <u>Piezoelectric Igniter</u>. This device would be located within the inflators of the air bag, and would be wired into the squib used to trigger the inflator. The piezoelectric crystal generates a high voltage, low amperage current when it is mechanically deformed. This system could be used to deploy air bags either at the dismantler/recycler or at shredder operations. Deployment at the dismantler/recycler would be by a remote piezoelectric igniter attached directly to the squib leads. Alternatively, deployment at shredder operations would occur automatically when the igniter is mechanically deformed by the shredder blades. The advantage of this system is its flexibility for application plus the automatic deployment features associated with shredding process.

3. <u>Electronic Keyhole-less Lock</u>. The keyhole-less lock contains an electromagnetic coil, code identification circuitry, and a bolt actuation mechanism. The key has a source of electric power, electronic coding circuitry, and an electromagnetic transmitting coil. The key is used to actuate the air bag through the keyhole-less lock at the time the car is brought into the scrapyards. Work will be needed to ensure that extraneous electromagnetic radiation will not inadvertently deploy the air bags. Physical contact between the key and the lock is required.

4. Self-Igniting Match Pyrophoric Added to the Pyrotechnic Material in the Inflator. The addition of a self-igniting match to the pyrotechnic gas generant provides a mechanism to initiate ignition of the generant during shredding, baling, or shearing of retired cars with undeployed air bag inflators. The match must be calibrated to ignite at the energy level associated with the deformation of the inflator module. Work will be needed to ensure that the addition of a self-igniting match, which must be chemically compatible with the gas generant, will not change the quality of the generant gas during normal crash deployment of the air bags. As with the piezoelectric ignitor, this system would automatically dispose of the sodium azide as the vehicle is shredded.
5. Induction Coil. In order to use this technique, the inflator module must be modified to incorporate a separate circuit consisting of an induction coil and a magnet. A special shield is required to prevent inadvertent deployment. Physical contact between the coil built into the module and an external coil is required to transmit the energy needed to ignite squibs.
6. Ultraviolet Radiation. There are many categories of electromagnetic radiation that could be used to deploy air bag inflators in retired cars. Ultraviolet radiation is one of them. The application of this energy source would require redesign of the squib and inflator module to include an optical window. A receiver must also be added to the system's electronics to make remote deployment possible. Special training programs are needed for the workers and provisions must be made for eye and skin protection.

7. Radio Frequency Tuned Squib. Radio waves are another source that could serve to activate the automatic deployment of air bag inflators in the retired cars. The application of this energy source requires that the squib be specially modified to include filters and electronics to tune deployment to a specific signal. Work will be needed to ensure that extraneous electromagnetic radiation could not inadvertently deploy the air bags.

8. Pulsed or Continuous Laser. This system would be similar to the system using electromagnetic radiation except that the source of such radiation would be a laser.

9. Microwave Radiation. This system is also a form of electromagnetic radiation. Since the microwave energy is transmitted by television and radar transmitters, there may be a high probability for inadvertent deployment of air bags with this system.

10. Ultrasonic. An ultrasonic transmitter could be employed to provide the stimuli to ignite the squib. Since ultrasound does not provide a high level of energy, the inflator module must be modified to include the appropriate receiver and circuitry in order to provide the energy to deploy the bags when the ultrasonic signal is received. The deployment process is fully automatic, and no physical contact with the inflator is required. Since the inflator module consists of a massive steel housing, a substantial signal would be needed to penetrate the thick steel housing. This requirement plus a variety of potential deployment sources in the environment (burgler alarms, remote control TV tuners, etc.) make it a less attractive option.

11. Collapsible Partition. This is another concept that provides a basis for automatic deployment of air bag inflators in retired cars during the reclamation process. The collapsible

partition consists of a deformable housing that incases the inflator module, sensing device, and electronics. When the sensing device detects a given level of structural deformation, the electronics would transmit a signal to actuate deployment of the air bag. Since there are many potential problems associated with the application of this technique, further work will be needed to study the viability of this approach.

The 12-volt dc system appears to offer the only approach that is now available for application to deploy retired inflator modules. Several other devices, including those with deployment principles based upon piezoelectrics, electronic locks, pyrophoric additives, and induction coils provide viable alternatives that could be developed and implemented during a 1 to 3 year period while the use of electromagnetic radiation, ultrasonics, and collapsible partitions would require a longer time frame for implementation.

CONCLUSIONS

There has been relatively little research directed toward identifying those hardware modifications that could be incorporated into existing inflator designs to ease the deployment of the retired module. Several individuals and companies involved in the current programs for automatic restraints were contacted to obtain information about how inflator hardware could be redesigned to ensure deployment during scrappage. Based upon these communications it is apparent that the automotive industry and their vendors have devoted a majority of their energies toward ensuring the reliability of inflators during normal use. A brief survey of the more prominent participants in inflatable restraint research and development programs indicates that the design configurations described in this program are representative of the hardware options that manufacturers could adopt for their inflator module hardware specifications.

RECOMMENDATIONS

This program has identified and evaluated various hardware designs that can be incorporated into the inflatable restraint systems to ensure safe deployment of the retired inflator module. The available alternatives were evaluated and ranked according to a selected qualitative scoring criteria. It is appropriate to examine these alternatives and assess their individual merits in more detail. The completion of this analysis would then provide a basis for undertaking further development work to design, build and test prototype inflator systems incorporating modifications that would assist in safe disposal.

1. RISKS ASSOCIATED WITH THE HANDLING AND DISPOSAL OF AIR BAG INFLATOR MODULES

1.1 Introduction

U.S. automobile manufacturers are required by the provisions of Federal Motor Vehicle Safety Standard 208 to provide passive passenger restraint systems in their large-size 1982 model year automobiles. Passive restraint systems are understood to be those which provide protection under specific collision conditions to the driver and front seat passengers without requiring the overt involvement of either individual with the restraint system. Current designs for passive restraints include configurations based upon the concept of passive belts as well as those incorporating the principles of the inflatable restraint or air bag restraint systems (ABRS).* The air bag systems can be further broken down into individual designs based upon either hybrid or pyrotechnic specifications. The hybrid devices utilize chemical gas generants to augment stored compressed inert gas such as argon or nitrogen. Current pyrotechnic models incorporate the sole use of solid propellant (e.g., sodium azide) as a direct gas (primarily nitrogen) generant.

1.2 Previous Studies

Several research programs have been undertaken by the automotive industry to identify and evaluate the potential risk to people, property, and the environment which result from the widespread application of inflatable restraint systems. These studies sponsored by the Motor Vehicle Manufacturers Association (MVMA) as well as individual companies have served to identify a variety of potential problem areas associated with the inflatable restraint systems. Many questions have also been raised regarding the relative toxicity of the generant chemicals, the potential impacts associated with the disposal of non-deployed inflator modules, and the necessity to develop rigid procedures for insuring the safe handling and disposal of retired inflators. Individual studies performed

*The terms inflatable restraints and air bag restraints are used interchangeably in this report.

by Arthur D. Little, Inc., (ADL)[1], Battelle [2], and Thiokol [3], reinforce the position adopted by many, including the Institute of Scrap Iron and Steel (ISIS), the Automobile Dismantlers and Recyclers of America (ADRA), Allied Chemical Corporation, Talley Industries, and others which strongly suggest that additional studies should be undertaken both to identify the risks associated with air bag restraint systems and to develop programs and procedures which are necessary to minimize the levels of these risks.

The majority of the previous research on passive restraints has encompassed a comparison of the risk tradeoffs between pyrotechnic and hybrid designs. Each design is unique in terms of both its hardware configurations as well as potential handling and disposal problems. However, the automotive industry has recently selected the pyrotechnic design for incorporation into their 1982 model passenger vehicles and this decision has encouraged the principle manufacturer of hybrid designs to disband all development efforts related to passive air bags. Therefore, it appears that the passive air bag restraint system installed in 1982 vehicles will be based upon the use of sodium azide as the pyrotechnic gas generant.

1.2.1 Problem Definition

There are several areas of concern associated with the utilization of pyrotechnic air bags as passive restraint systems. These primary concerns relate to all stages of the vehicle life cycle including normal consumer use, abandonment, dismantling for recycling of parts, scrapyard fragmentation of vehicle hulks, and ultimate remelting of ferrous and non-ferrous scrap to complete the automobile recycling process. The relative mangnitude of the various problems and hazards associated with the pyrotechnic inflators is based upon a consideration for several factors including the number of modules which must be handled and disposed, the nature of the hazard associated with each stage of the life cycle, and the probability for the occurrence of a particular event.

1.2.2 Analytical Procedures

Previous work undertaken by ADL has been utilized to identify the individual risks associated with pyrotechnic air bag inflators. These risks are based upon the development of a quantitative life cycle model, a series of impact matrices, and a modified fault analysis which identify for each stage of the vehicle life cycle the probability for a given event, the nature of the associated risks, and their severity.

- Life Cycle Model - A quantitative model was constructed to evaluate various events in the ABRS life cycle including entrance to and exit from the population of vehicles "in use", and other events in the life of a vehicle. The events are in two classes: possible events during the useful life of a vehicle; and the certain event of the eventual retirement of the vehicle. Possible events include collision, air bag deployment, and fire. Retirement has been defined in terms of three possible end states: abandonment, active parts salvaging (dismantling/recycling), and metal reclamation (i.e., shredding, baling operations).

- Risk Assessment Matrix - The risk assessment matrix is developed based upon consideration for the proability for the occurrence of a given life cycle event, the conditional probability of a subsequent hazard event, the assessment of the severity of the event and identification of the population at risk. These factors are considered simultaneously in developing an assessment of the net risk of a particular event. This form of analysis is then continued for the various events which can occur during each stage of the life cycle.

- Impact Event Matrix - The impact/event matrix provides a mechanism to display pictorially the results of certain events encountered during the air bag life cycle. This translation from the narrative to a visual presentation provides a convenient mechanism for observing where and to what degree risk to various receptors (humans, biotic, and physical environment) is concentrated within the various stages of the ABRS life cycle. For example, if a particular stage in

the life cycle (e.g., scrapyard operations) results in elevated levels of risk to operating personnel, then this factor would be prominently displayed on the impact matrix for this stage of the life cycle. Correspondingly, if the undertaking of scrapyard operations results in environmental pollution of land, air or water, then this information would be appropriately displayed within the body of the impact matrix. A separate impact matrix has been developed for each stage of the ABRS life cycle and these individual matrices have been summarized in a final overall impact assessment matrix which identifies in a semi-quantitative fashion those areas where the anticipated impacts of ABRS during normal use and disposal are highest.

- <u>Fault Tree Analysis</u> - The fault tree is utilized in two principal types of application. First, it is employed to assess the overall risk of occurrence of a certain undesirable event. Second, the fault tree provides a mechanism for the systematic examination of an event (deployment during scrapyard operations) for the purpose of discovering the various modes by which the event can occur and identifying the critical or most important areas of concern. The overall fault tree consists of an undesired top event (e.g., employee exposure to generant chemicals) and identifies the contributing events. The tree may be broken into subtrees if this is convenient, either because additional detail is required or because it is not possible to display all critical events on the original tree. All events leading to the undesired event are considered as second level events which are connected to the top event through a series of logic gates referred to as "or" gates or "and" gates. This basic procedure of determining alternative relevant cause of an event and connecting these events through logic gates is continued until all events are fully developed.

1.3 Results of Previous Studies

A life cycle model developed by ADL for the MVMA was applied to identify for the years 1981-2001, the percentage of the U.S. passenger car fleet equipped with the air bag restraints, the rate of voluntary retirement of air bag equipped vehicles, and the rate of vehicle retire-

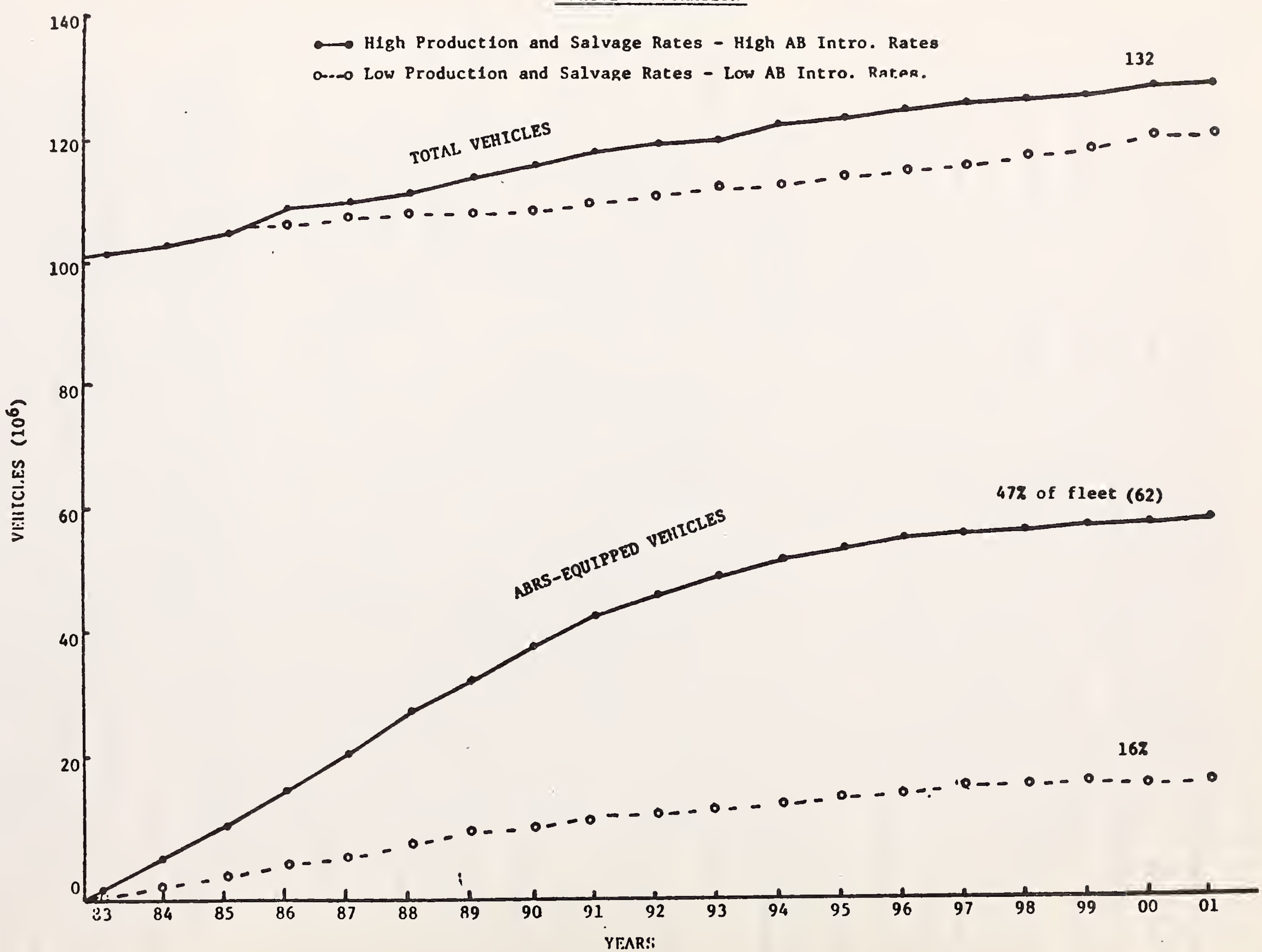
ment associated with fire or collision conditions. Graphical plots of these data are presented in Figures 1-1, 1-2, 1-3, and indicate that in the future, there is the potential that a large proportion of the U.S. passenger car fleet may be equipped with air bag restraints and secondly, that during the late 1980's, millions of vehicles containing non-deployed air bags will be retired from normal use. These observations regarding the vehicle life cycle, coupled with an awareness of the potential hazards associated with gas generant chemicals, has aroused concerns regarding the ability of automobile dismantlers, scrapyard operators, and others engaged in the recycling process to adequately address the potential problems associated with the safe handling and disposal of retired air bag inflator modules.

The scrapyard and automobile dismantling operations are representative of particular stages in the vehicle life cycle where both employees of the scrapyard and the physical environment encompassing the yard could become adversely effected through exposure to the pyrotechnic gas generant contained within the inflator module. The risk assessment matrix, impact/event matrix and modified fault tree for scrapyard operations are presented in Tables 1-1 and 1-2, and Figure 1-4. This package of information is a representative of the analytical process which was employed to assess the risks to people, property and the environment. A comparable level of analysis was undertaken for each stage of the air bag life cycle and the results are presented as an overall impact matrix.

The summary impact/event matrix for the pyrotechnic ABRS presented in Figure 1-5 indicates that a majority of the risks associated with these systems are related to operations conducted during dismantler/recycler and scarpyard phases of the life cycle. Furthermore, the major health impacts are related to potential human exposure to pyrotechnic generant chemicals. The risks associated with exposure to the gaseous effluents following the intentional deployment of the inflator appear to be less severe. These observations suggest that any programs to reduce the risks associated with the use of passive air bag restraints should focus attention initially upon dismantler/recycler and

Figure 1-1

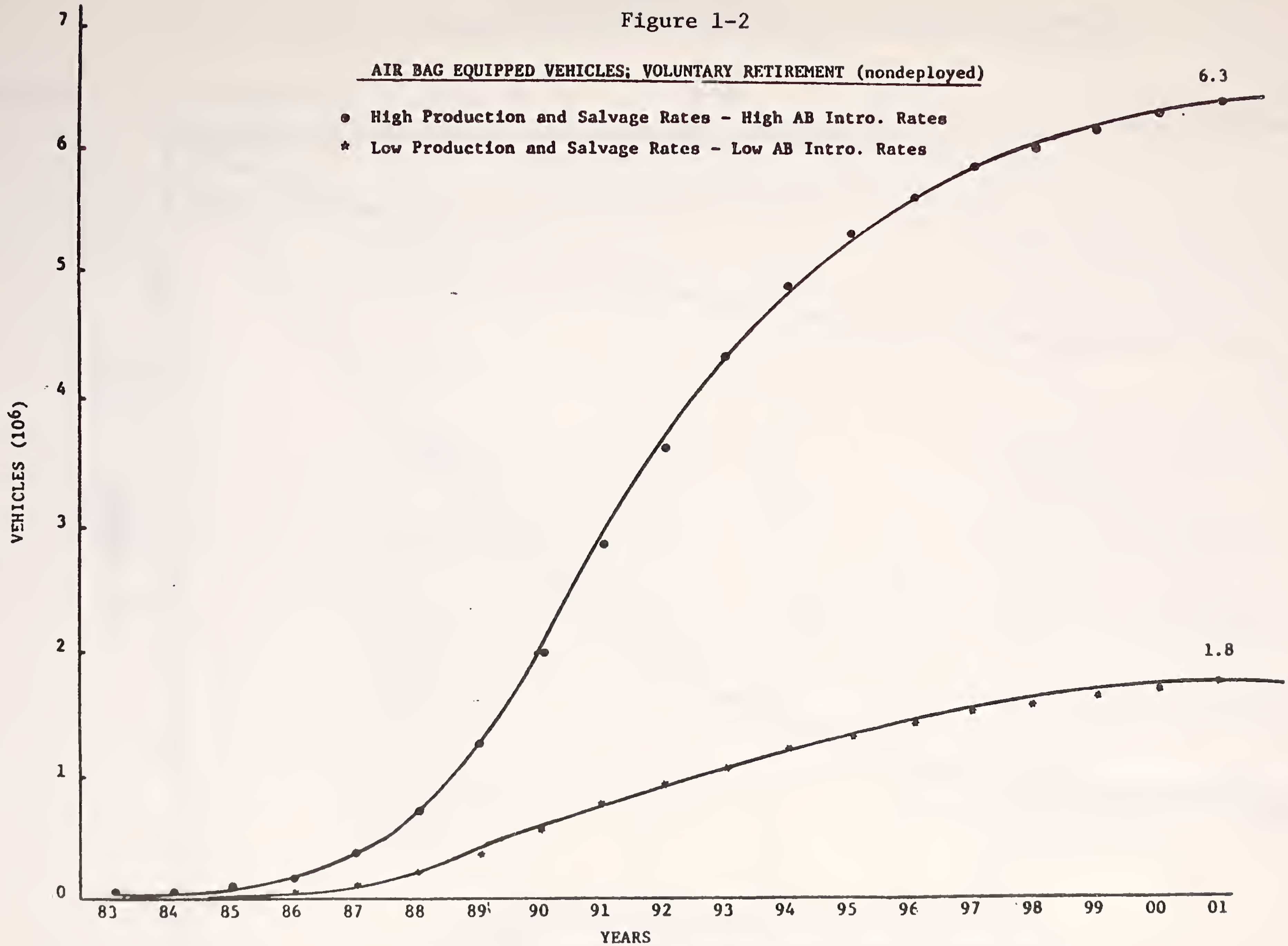
VEHICLE POPULATION



Source: Arthur D. Little, Inc. estimates based upon available information.

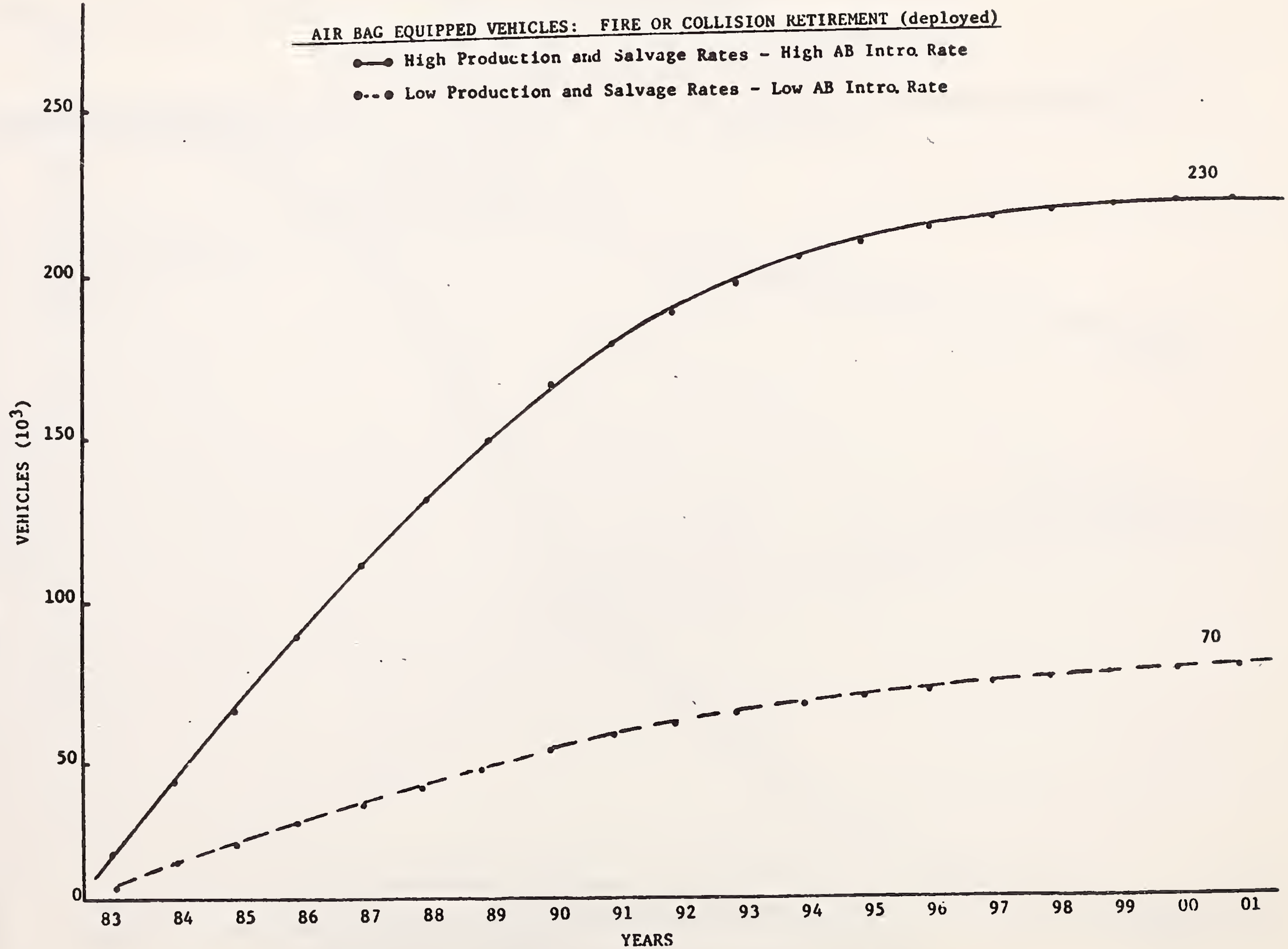
Figure 1-2

AIR BAG EQUIPPED VEHICLES; VOLUNTARY RETIREMENT (nondeployed)



Source: Arthur D. Little, Inc. estimates based upon available information.

Figure 1-3



Source: Arthur D. Little, Inc. estimates based upon available information.

Table 1-1

RISK ASSESSMENT MATRIX
PYROTECHNIC/SCRAPYARDS

RISK ASSESSMENT: PYROTECHNIC SYSTEM

Life Cycle	Event	Probability	Event	Probability	Potential severity of the event	Population at risk	Net risk	Comments on net risk
Scrap Yards	Inflator deployment	L	Acute exposures	M	M	L	M	Few non-deployed inflators will reach this stage. Rapid dilutions expected.
			Air pollution	M	L	L	L	Low volume and dilution minimize effects of point source air pollutions.
	Deployment of structurally damaged inflator	L	Initiate projectile motion	L	H	L	L	Projectile hazard during shredding or prior to baling.
			Explosive fragmentation	L	H	L	L	Shrapnel hazard during shredding or during removal of inflator from waste stream.
	Release of generant during scrap processing	H	NaN_3 exposure	M	M	L	M	Hand sorting of non-ferrous fraction may lead to chronic exposure.
			Process water contamination	H	L	L	L	Hydrazoic acid may form under acid conditions. Rapid dilution is expected.
			Site contamination	M	L	L	L	Limited accumulation of NaN_3 because of short environmental half-life.
			Ignition of accumulated generant	M	M	L	M	Repair operations may ignite accumulated generant in process machinery.
			Formation of heavy metal azides	L	H	L	M	Lead or copper azides may form under specific conditions of pH and ion concentration. Detonation will occur without much accumulation.
			Air pollution	L	M	L	L	See above.
			Generant in fluff material	H	M	L	M	Risk in transfer to landfill or refuse derived fuel facility, may be treated as hazardous waste.

Source: Arthur D. Little, Inc. estimates based upon available information.

Table 1-2

IMPACT MATRIX
PYROTECHNIC/SCRAPYARDS

Events / Impacts		Physical						Biotic				Human			
		Land		Water		Air		Fauna		Flora		Health		Safety	
		Surface	Subsurface	Surface	Ground	Particulate	Gaseous	Aquatic	Terrestrial	Aquatic	Terrestrial	Acute	Chronic	Injury	Fatality
Life Cycle	Initial* Final														
Scrapyards	ND .108 .071				?								?		
	D .036														
	DD 5.46 5.5														

* 10^6 Vehicles
ND - Nondeployment
D - Deployment
DD - Deployed

Potentially present (hatched box)
Unlikely (blank box)
Questionable, and requiring further evaluation (hatched box with ?)

Figure 1-4

FAULT TREE
CHRONIC EXPOSURE TO GENERANTS DURING DISPOSAL

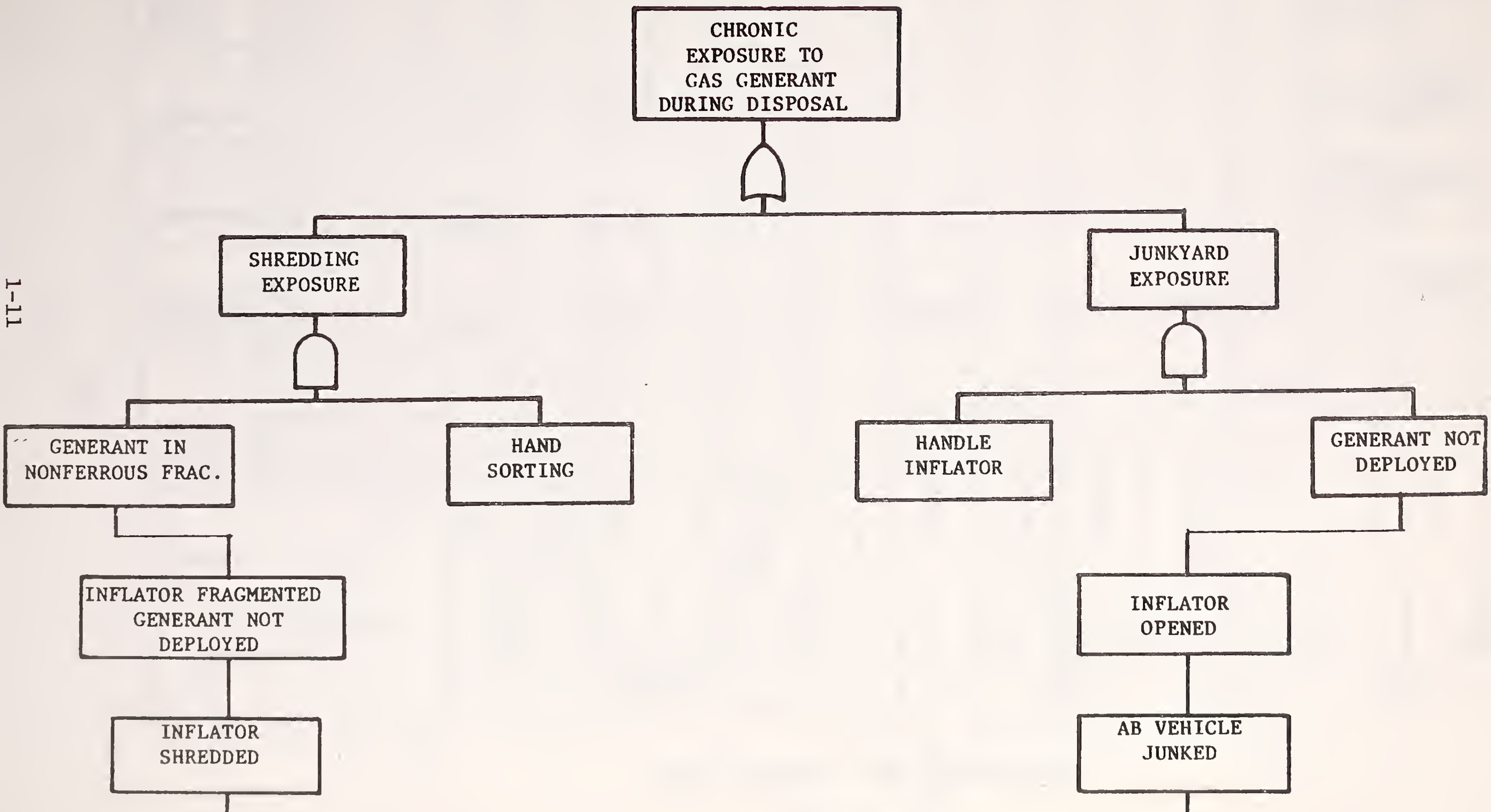


Figure 1-5

IMPACT MATRIX - PYROTECHNIC ABRS

Events ↓ / Impacts →			Physical						Biotic				Human			
			Land		Water		Air		Fauna		Flora		Health		Safety	
			Surface	Subsurface	Surface	Ground	Particulate	Gaseous	Aquatic	Terrestrial	Aquatic	Terrestrial	Acute	Chronic	Injury	Fatality
Life Cycle		Initial* Final														
Intended Use	ND	62 60														
	D	2											/?/			
	DD	0 2														
Abandoned & Graveyard	ND	1 1	///		///				/?/		/?/	///				
	D	?											/?/		///	
	DD	.036 .036														
Junkyards	ND	5.4 .108	///		///									/?/		
	D	5.3												/?/	///	
	DD	.186 5.46														
Scrapyards	ND	.108 .071	///		///	/?/								/?/	///	
	D	.036													///	
	DD	5.46 5.5														
Metal Melting	ND	.071 0												/?/		
	D	.071													///	
	DD	5.5 5.57													/?/	

ND - Nondeployment
D - Deployment
DD - Deployed
*10^6 Vehicles

/// Potentially present
Unlikely
/?/ Questionable, and requiring further evaluation

scrapyard operations.

There are no well established programs to educate or train employers or employees involved in the automobile recycling industry of the potential hazards associated with air bag inflators. Furthermore, there is little lead time available to modify the design of the air bag system. Automobile manufacturers have made committments to equipment vendors for the 1981 model year systems and soon must be prepared to undertake similar actions for 1982.

Fortunately, the requirements for passive restraint systems provide for a phased program such that the regulations for intermediate and small vehicles become effective in 1983 and 1984 model years. Although the automotive manufacturers have finalized their system designs for the 1981 model year, there is still time available to consider possible hardware modifications for the mandated 1982 requirements. Also, the model for vehicle retirement indicates that 5 or 6 years are available before significant (greater than 1.0 million per year) numbers for air bag equipped vehicles are retired annually. Therefore, with appropriate planning, it is possible to identify various control programs which could be implemented to provide for the safe handling and deployment of retired air bag inflators.

In conclusion, motor vehicle manufacturers will be offering air bag restraint systems as options on some of their 1981 model large size passenger vehicles. In 1982, passive restraint systems are mandatory for large vehicles with phased implementation scheduled for intermediate and small vehicles. It is apparent, that if air bags are selected as the means for passive restraint, then there are several questions which must be answered regarding problems with the safe handling and disposal of retired air bag inflators. This analysis proceeds by identifying the various hazards associated with passive air bag systems, suggesting various programs which might be employed to safely handle and deploy retired inflators, and evaluating the probable effectiveness of each option.

REFERENCES AND SOURCES

SECTION 1.0

(1) Arthur D. Little Inc., "An Investigation of the Potential Human and Environmental Impacts Associated with Motor Vehicle Air Bag Restraint Systems", prepared for Motor Vehicle Manufacturers Association, December 1978

(2) Battelle Columbus Laboratories, "Gas Generants Research", Motor Vehicle Manufacturers Association, November 1978

(3) Thiokol, "Sodium Azide Investigation Program", Ford Motor Company, May 1978

2. HAZARD ANALYSIS

2.1 Introduction

The hazards associated with the safe handling and disposal of air bag inflators relate to acute and chronic exposures to dismantler employees plus possible environmental contamination. The degree of hazard can also vary depending upon the deployment procedures which are invoked by individual dismantlers. The specifics regarding alternative deployment procedures, their associated hazards, and appropriate countermeasures can be defined on a sequential or time phase specific basis. For a given event, three distinct time periods or time frames are recognized as important when formulating a control strategy to counteract or otherwise address a potentially hazardous event.[1] These individual time frames are identified as: (1) the pre-event phase, where measures are introduced to prevent the hazardous event from occurring; (2) the event phase, where countermeasures are intended to minimize the severity of exposure and the probability of injury and; (3) the post-event phase, where countermeasures are intended to reduce the results or consequences of injury. Some examples of time phase analyses for control of accidents are presented in Table 2-1. Here, the connotations of prevention, minimization of injury potential, and reduction of the unnecessary consequences of an event are clearly evident. This approach, incorporating a three-phase evaluation procedure, was employed to assess alternative strategies which could be employed to provide for the safe handling and disposal of retired air bag inflator modules.

The pre-event, event and post-event countermeasures for the safe handling and disposal of air bag inflator modules at automobile dismantler operations are shown in Figure 2-1. The specific recommendations for each countermeasure are then presented in Figures 2-2, 2-3, and 2-4. This information provides a pictorial representation of dismantler operations and illustrates the various programs or procedures which may be utilized to prevent or control the extent of hazards

TABLE 2-1

TIME-PHASE ANALYSIS FOR CONTROL STRATEGIES

TYPE OF EVENT	CONTROL STRATEGIES: PRE-EVENT	EVENT	POST-EVENT
Carbon monoxide poisoning	Vehicle design to prevent CO leakage into passenger compartment	CO detectors that turn off vehicle	Oxygen therapy Hyperbaric chambers
Chain saw lacerations	Chain saw blade guards	Rapid stop for blade Dead man's switch	Emergency first aid Blood transfusions Skin grafting
Burns	Eliminate space heaters. Elevate appliance pilot lights	Smoke detectors flame retardent clothing	Burn centers Skin grafting
Skiing Injury	Ski trail grooming	Safety bindings	Ski patrols
Motorcycle Injury	Speed governors Side cars	Crash helmets	Shock-trauma units Air ambulances
Heart Attacks	Reduce smoking Reduce cholesterol intake. Hypertension screening	Cardiopulmonary resuscitation	Cardiac emergency indications Emergency medical services
Choking	Cut food into small pieces. Chew food well.	Heimlich maneuver	Emergency tracheotomy

Source: Arthur D. Little, Inc. estimates based upon available information.

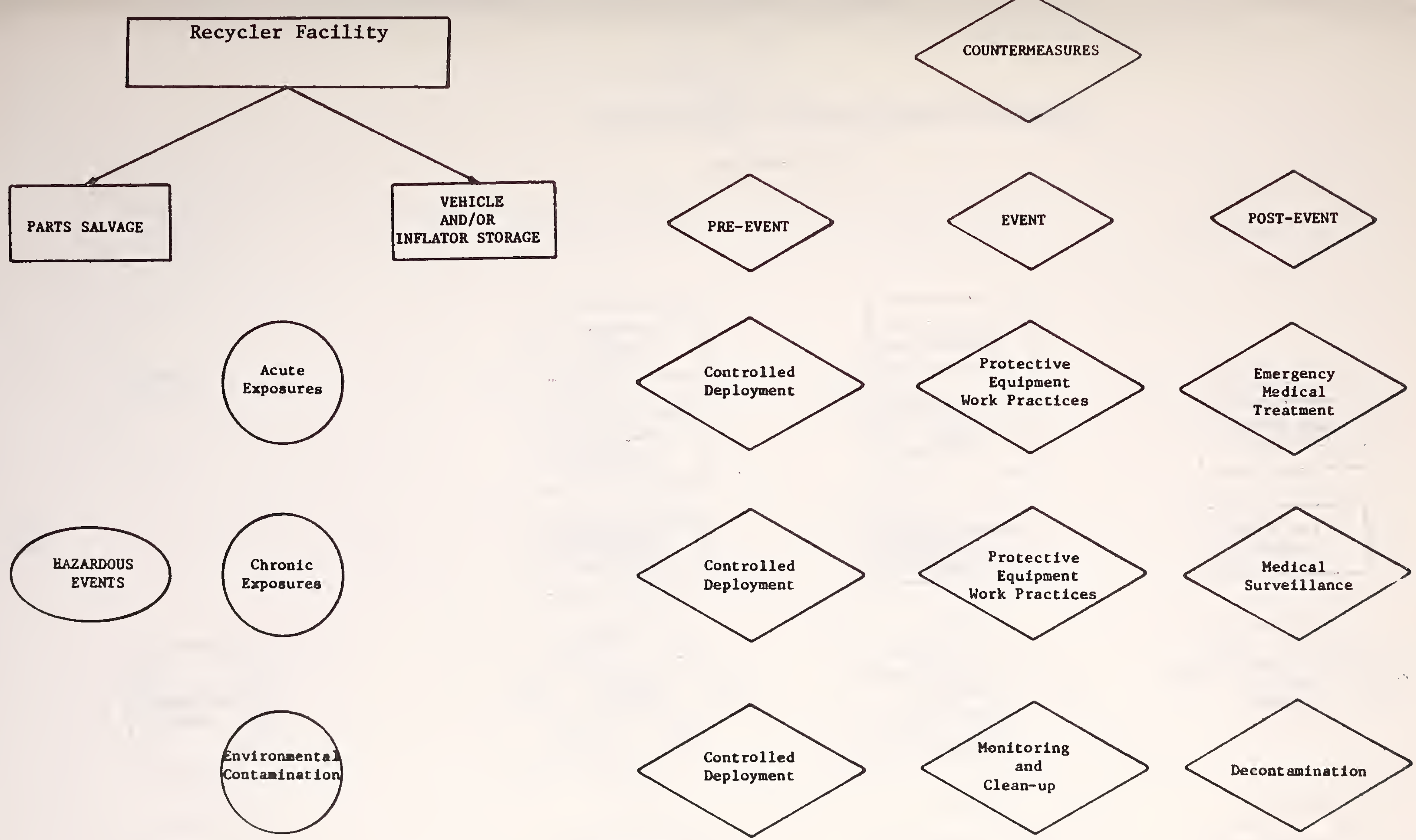


Figure 2-1

COUNTERMEASURE APPROACHES/DISMANTLER-RECYCLER

Source: Arthur D. Little, Inc. estimates based upon available information.

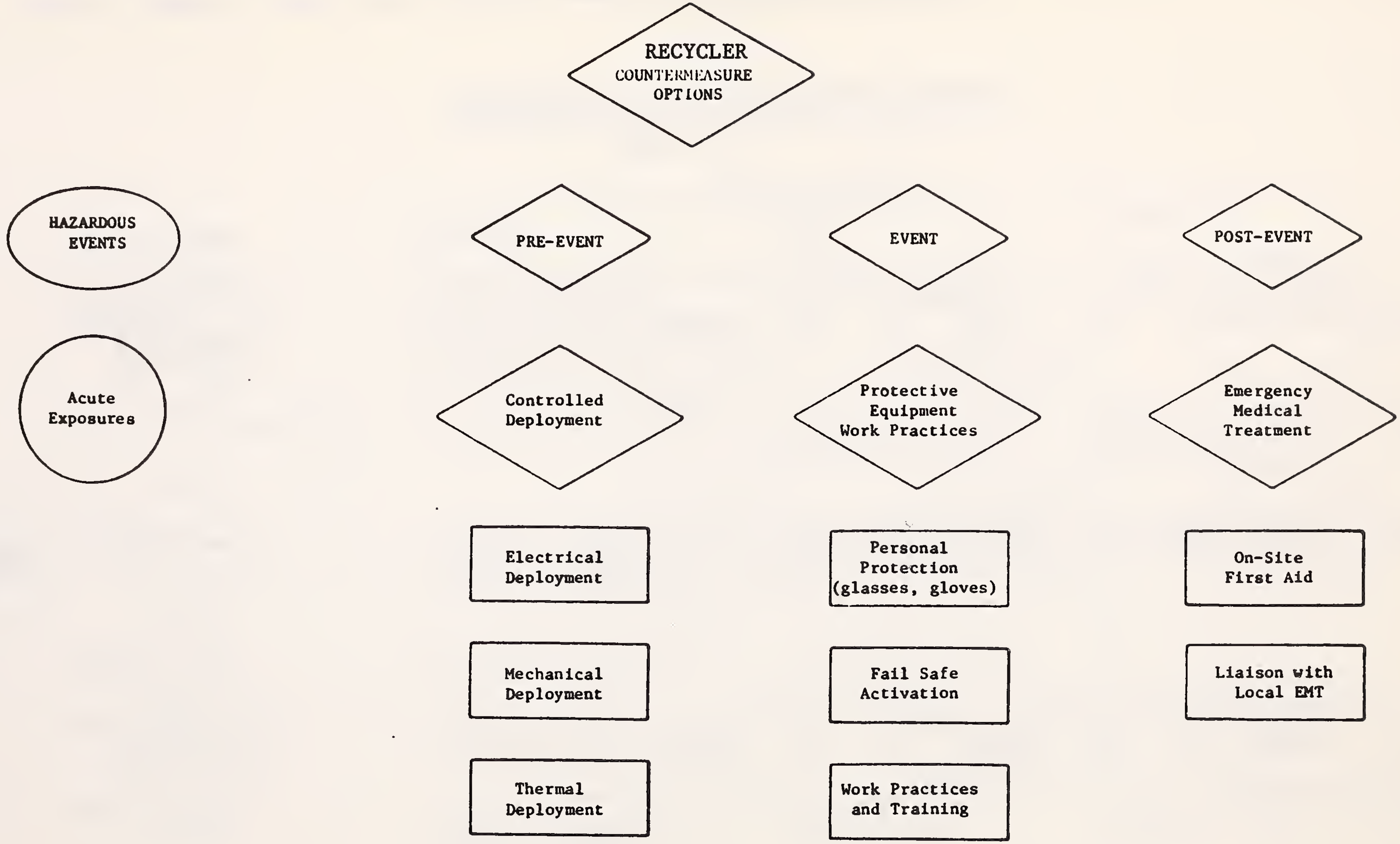


Figure 2-2

COUNTERMEASURE OPTIONS/DISMANTLER-RECYCLER

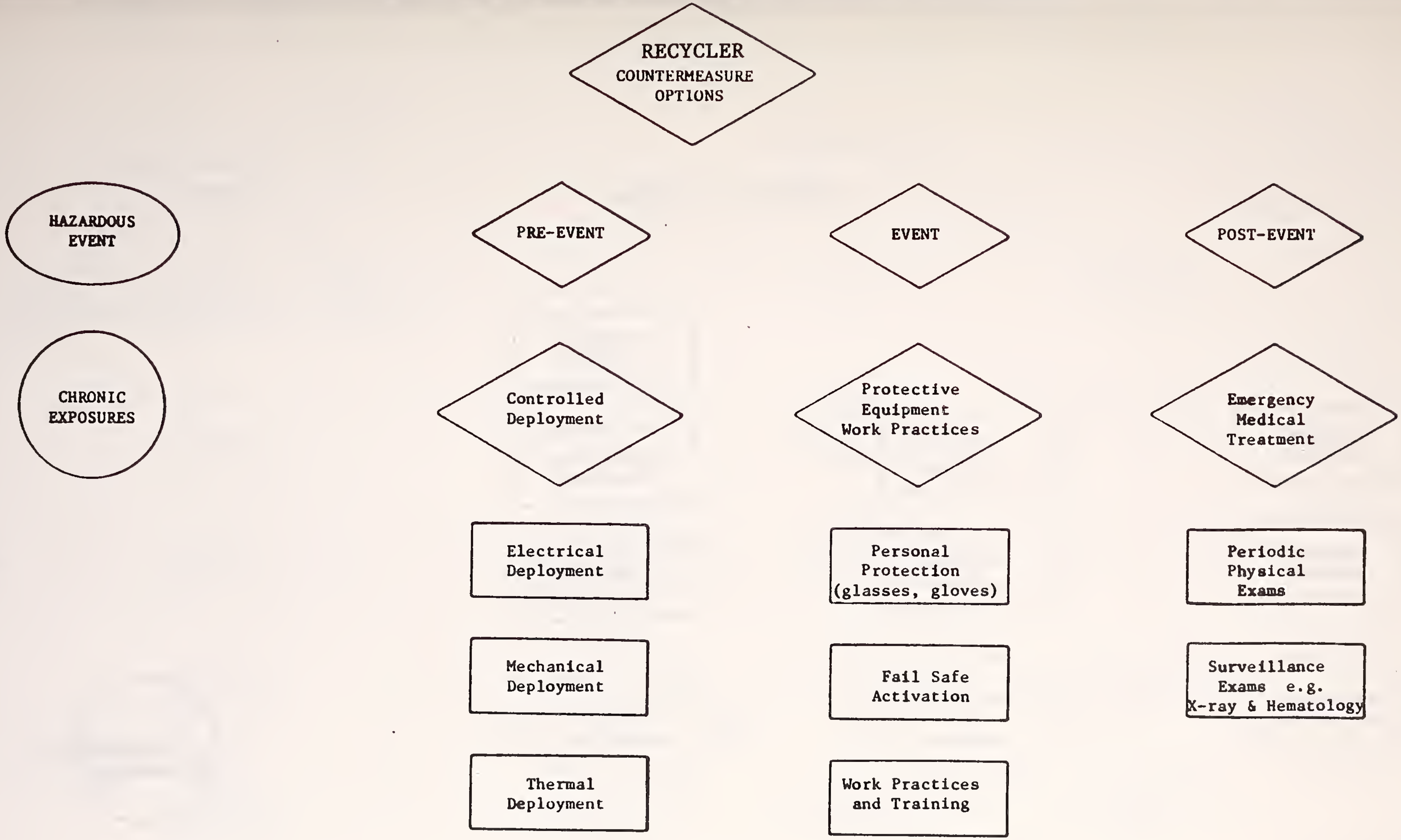


Figure 2-2 (Contd)

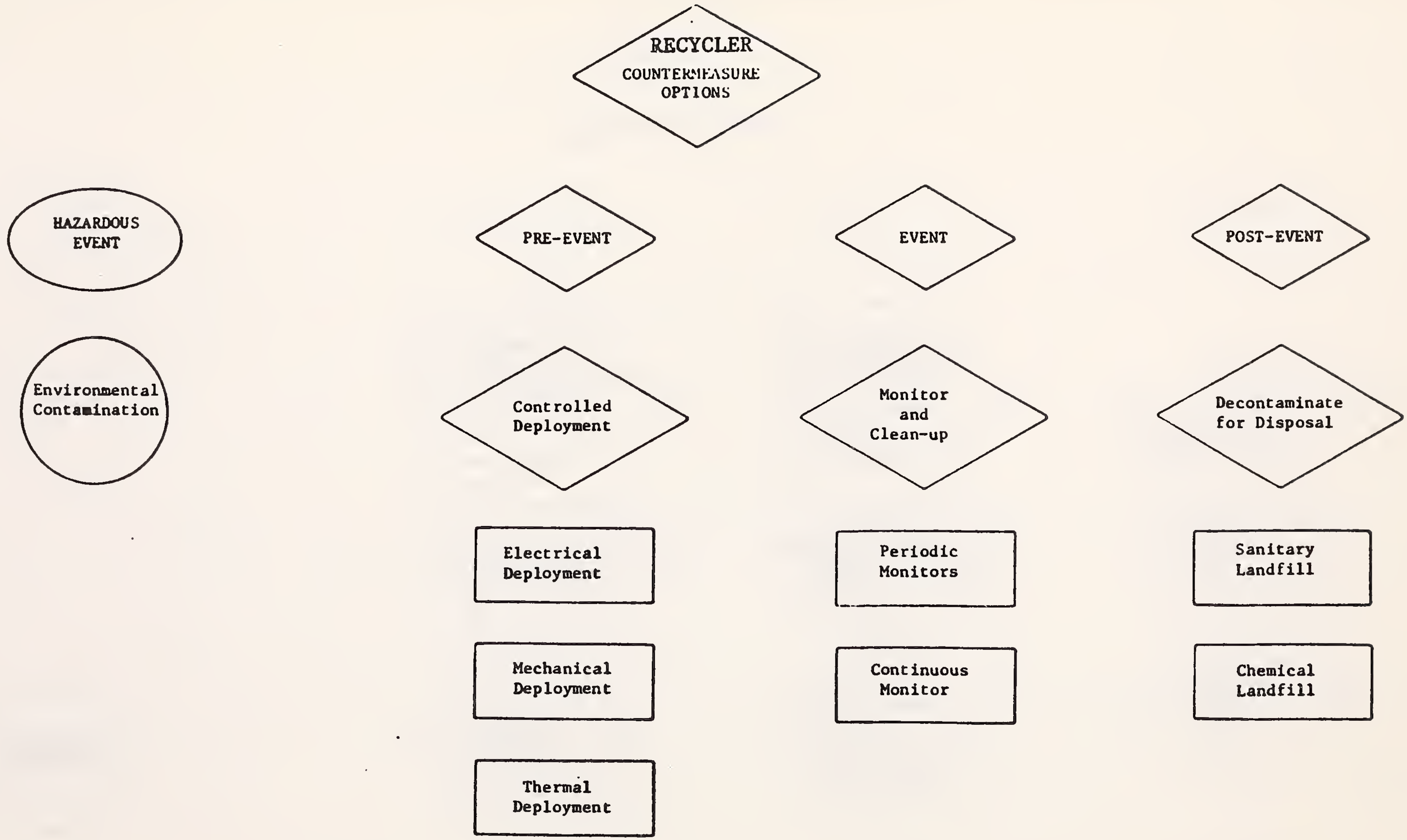
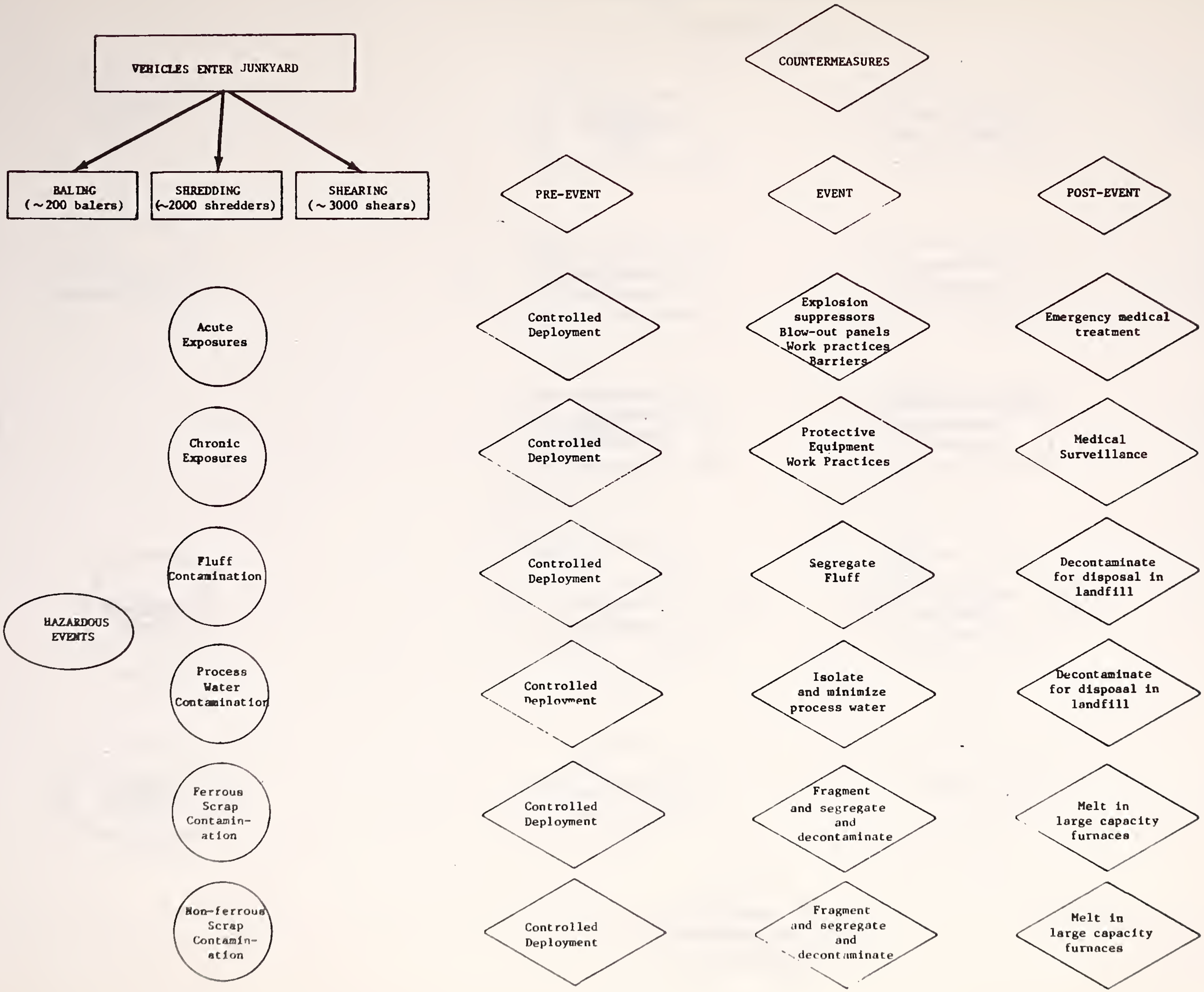


Figure 2-2 (Contd)

Source: Arthur D. Little, Inc. estimates based upon available information.


VEHICLES ENTER JUNKYARD
BALING (~200 balers)
SHREDDING (~2000 shredders)
SHEARING (~3000 shears)
COUNTERMEASURES
PRE-EVENT
EVENT
POST-EVENT
HAZARDOUS EVENTS
Acute Exposures
Controlled Deployment
Explosion suppressors Blow-out panels Work practices Barriers
Emergency medical treatment
Chronic Exposures
Controlled Deployment
Protective Equipment Work Practices
Medical Surveillance
Fluff Contamination
Controlled Deployment
Segregate Fluff
Decontaminate for disposal in landfill
Process Water Contamination
Controlled Deployment
Isolate and minimize process water
Decontaminate for disposal in landfill
Ferrous Scrap Contamin-ation
Controlled Deployment
Fragment and segregate and decontaminate
Melt in large capacity furnaces
Non-ferrous Scrap Contamin-ation
Controlled Deployment
Fragment and segregate and decontaminate
Melt in large capacity furnaces

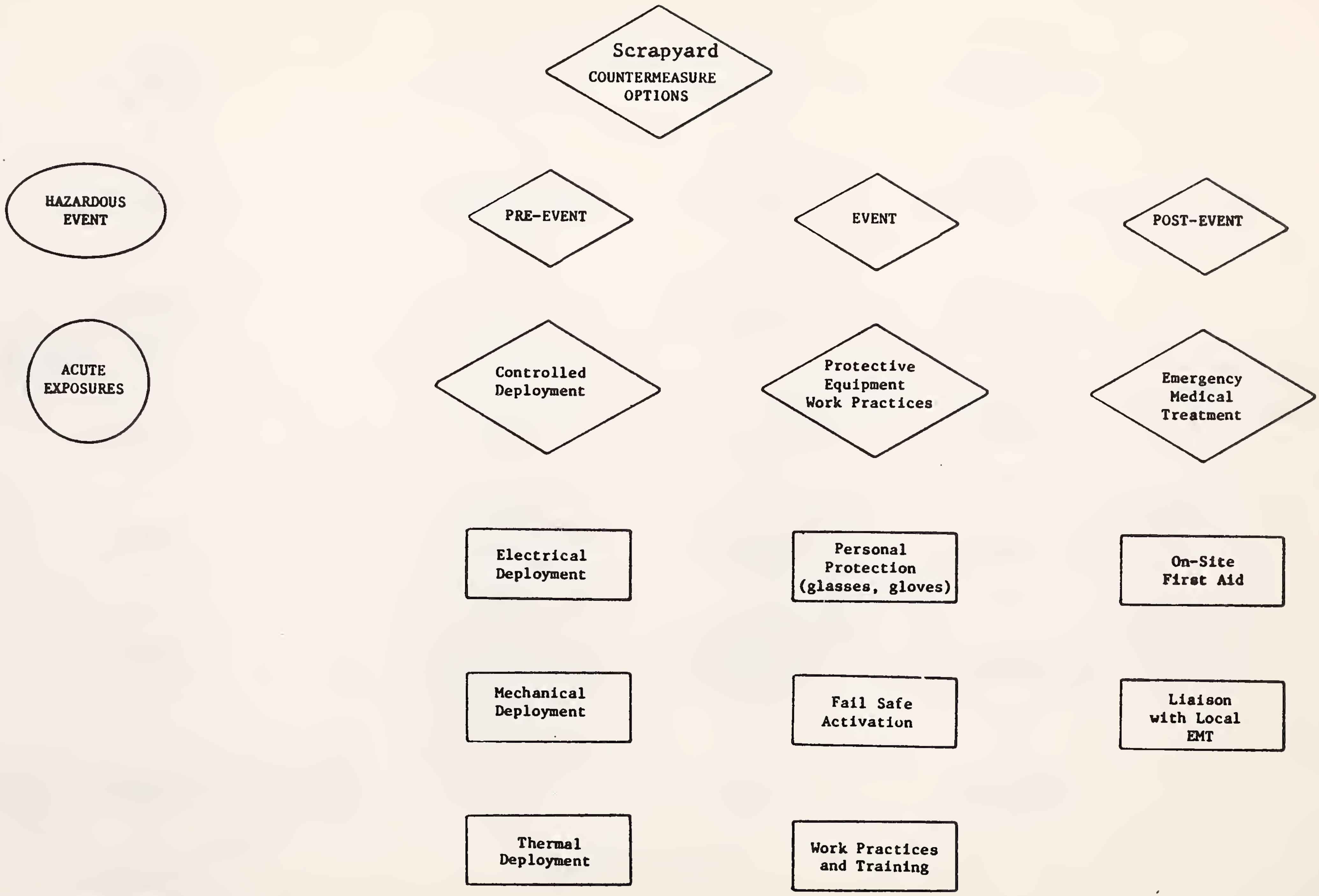


Figure 2-4

COUNTERMEASURE OPTIONS/SCRAPYARD

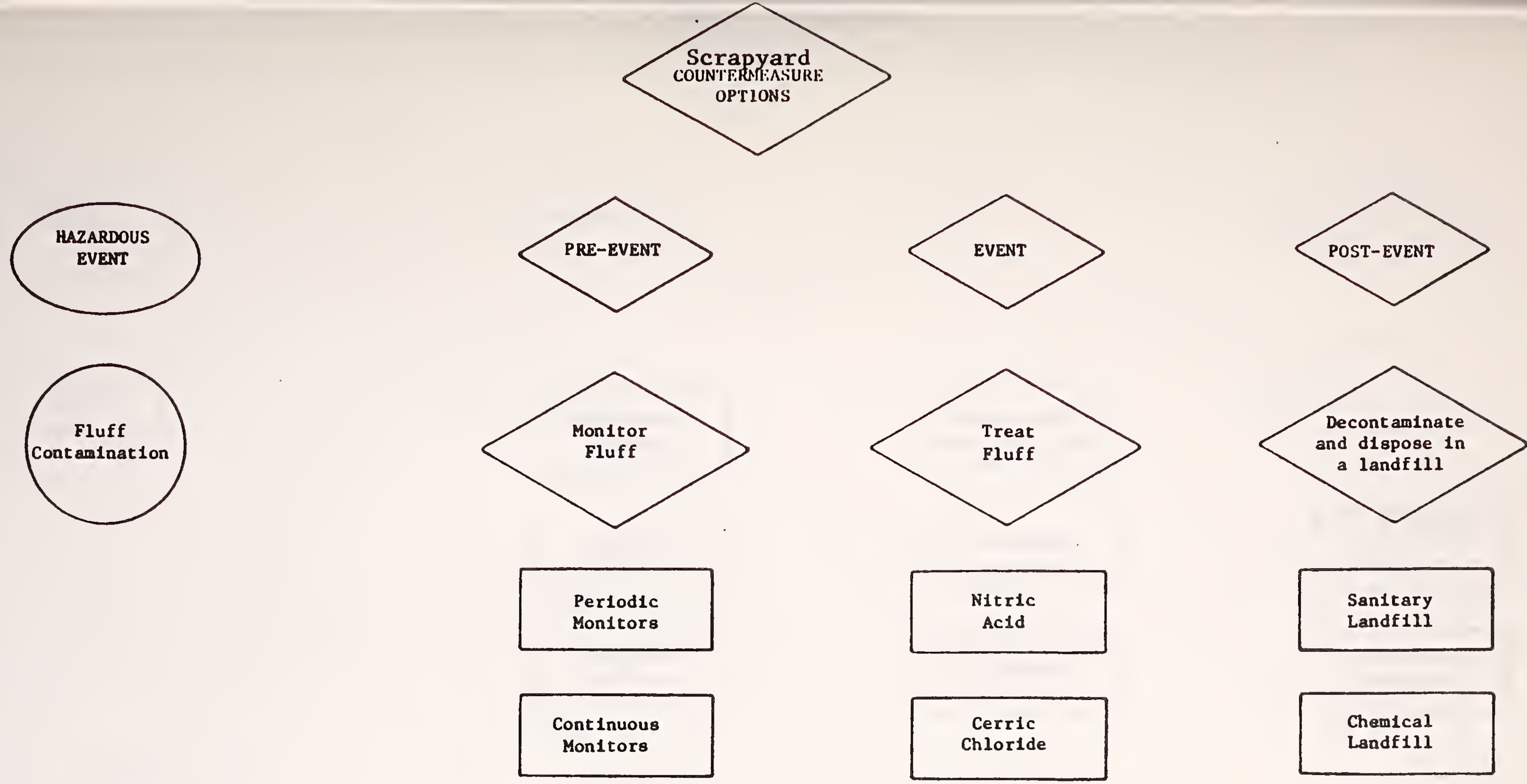


Figure 2-4 (Contd)

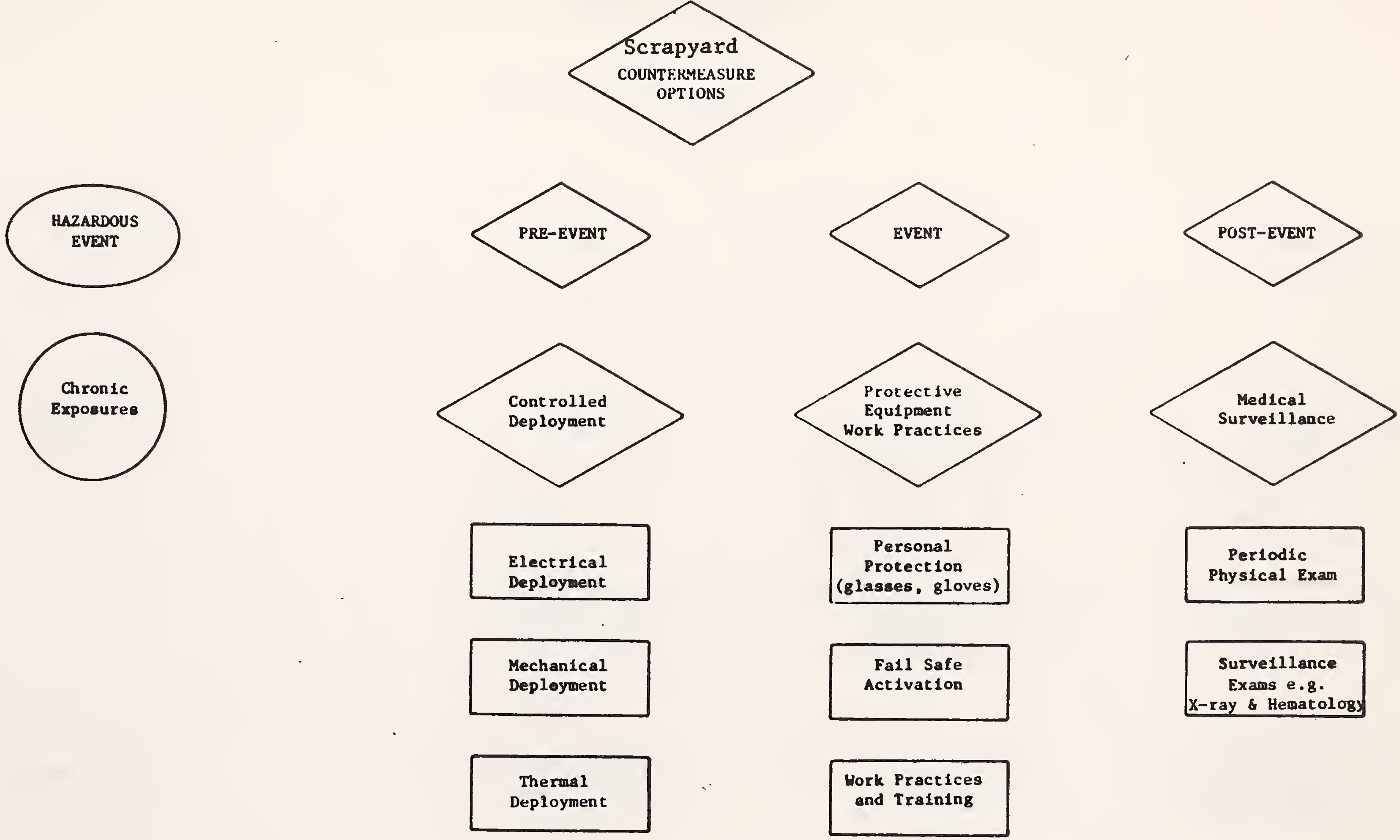


Figure 2-4 (Contd)

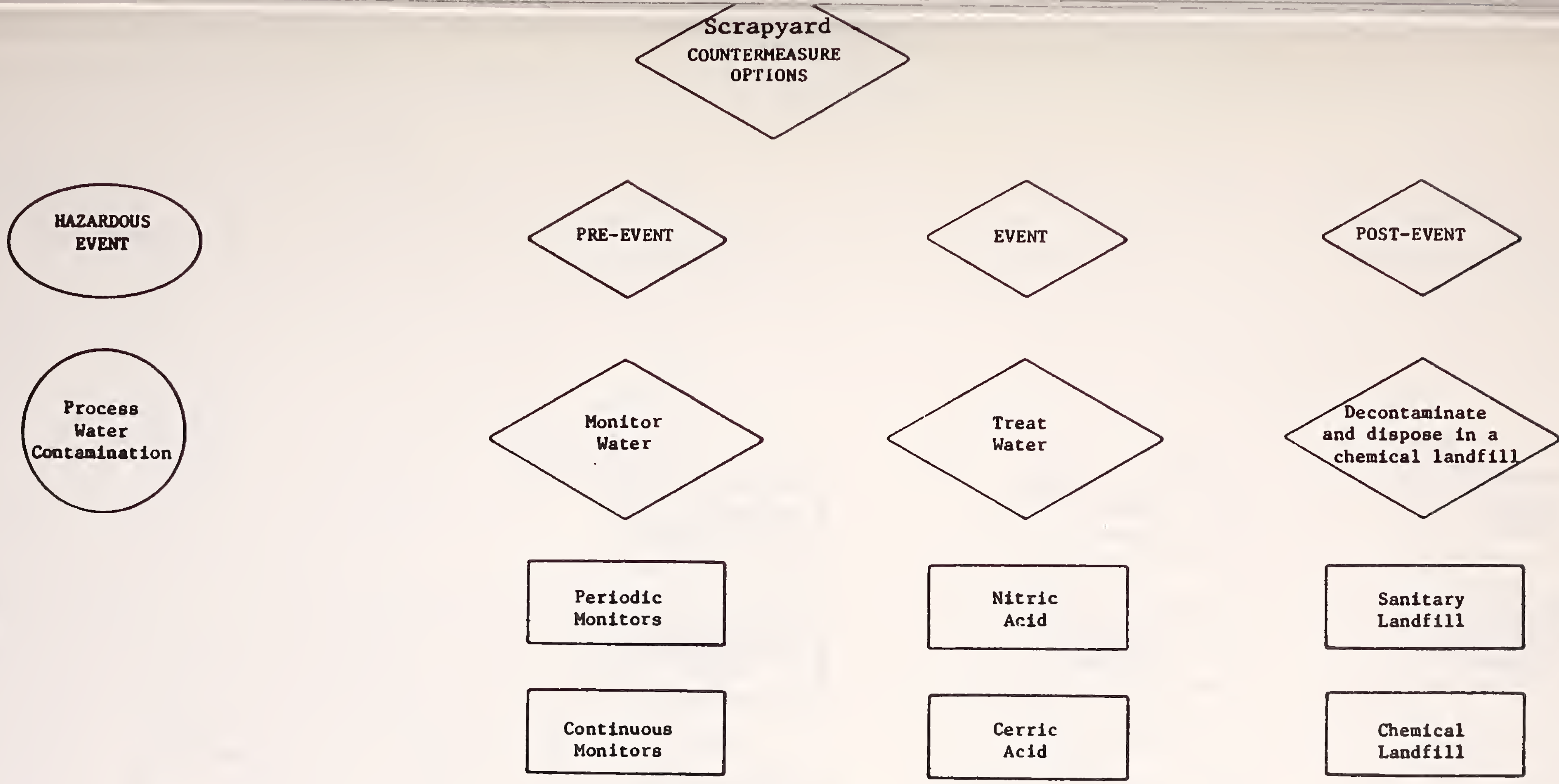
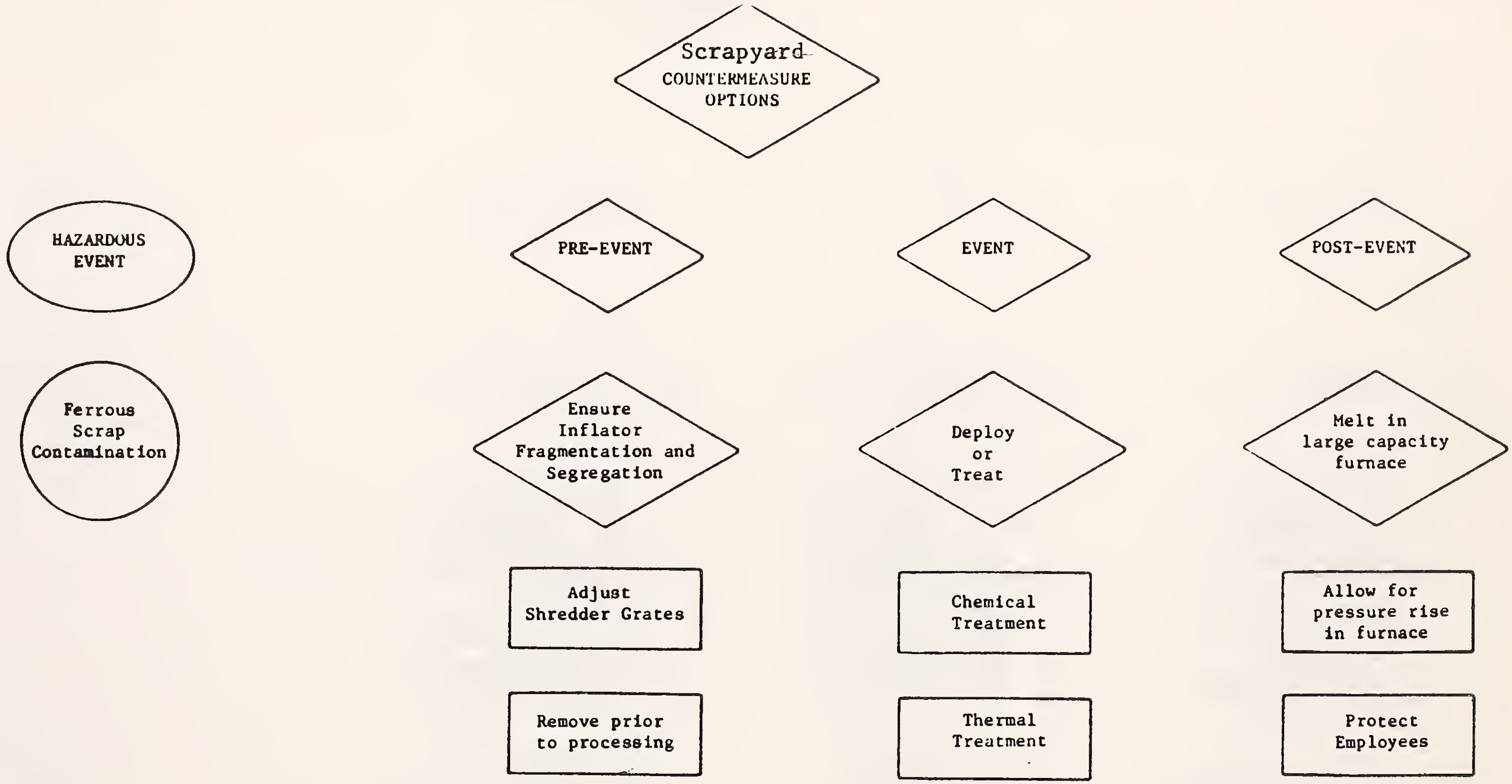
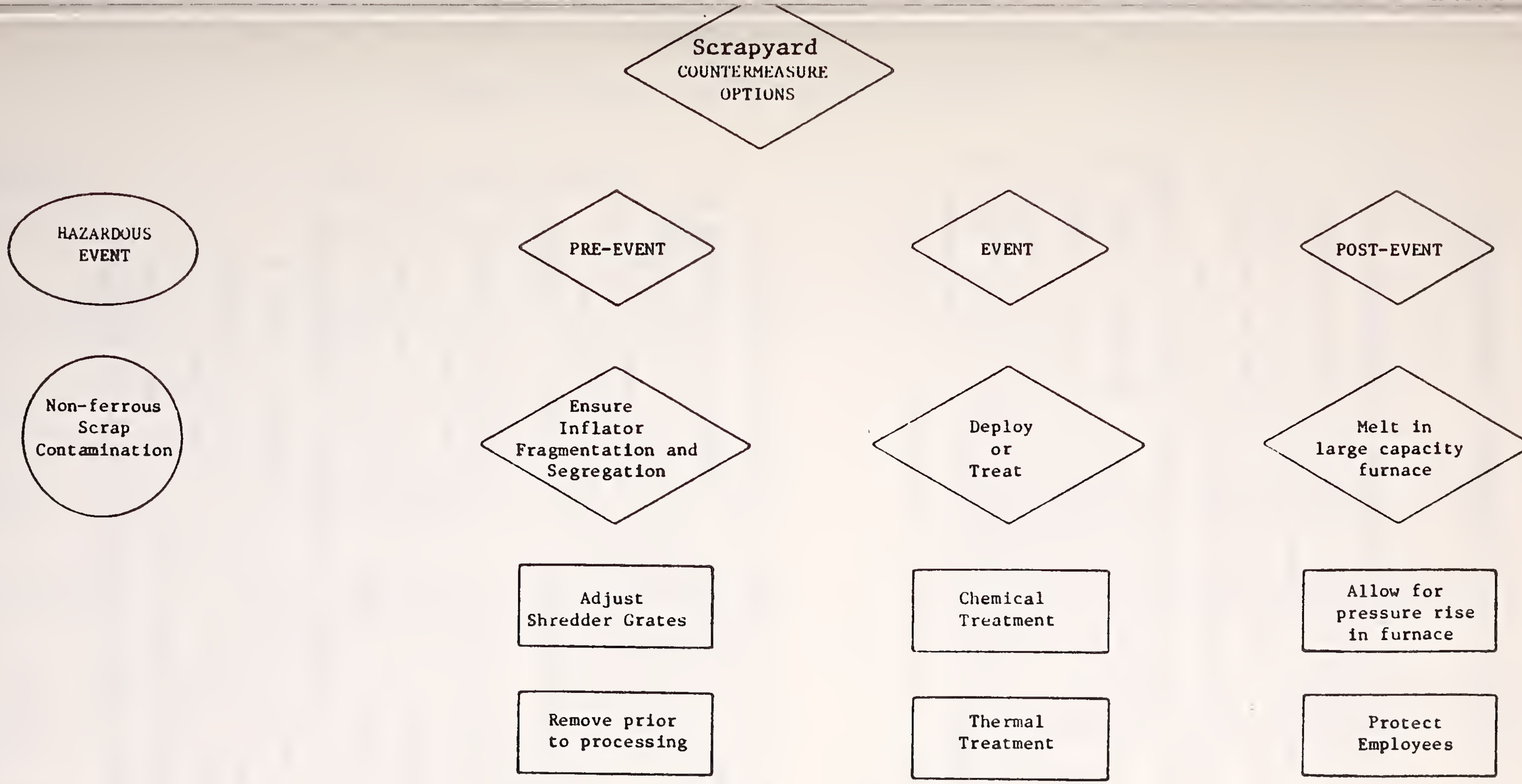


Figure 2-4 (Contd)


Scrapyard
COUNTERMEASURE OPTIONS
HAZARDOUS EVENT
Ferrous Scrap Contamination
PRE-EVENT
EVENT
POST-EVENT
Ensure Inflator Fragmentation and Segregation
Deploy or Treat
Melt in large capacity furnace
Adjust Shredder Grates
Chemical Treatment
Allow for pressure rise in furnace
Remove prior to processing
Thermal Treatment
Protect Employees



Source: Arthur D. Little, Inc. estimates based upon available information.

Figure 2-4 (Contd)

including employee injury of illness and environmental contamination.

2.2 Pre-Event Analysis

Employees engaged in dismantling of automobiles are exposed to a variety of toxic materials. Some examples of potential exposures are shown in Table 2-2. These situations are compounded when an air bag equipped vehicle containing sodium azide enters the dismantling process. Given the potential health hazards associated with azide, plus the potential for injury associated with projectiles which might be propelled during air bag deployment, it is obvious that the most desirable solution to the potential problems posed by handling retired air bag inflators involves interacting with the system during the pre-event stage of the countermeasure process. This pre-event countermeasure, identified as controlled deployment, is based upon the utilization of a deployment device which generates an external electrical, mechanical, or thermal stimuli to fire the inflator.

2.3 Event Analysis

Under certain conditions, either because the pre-event countermeasure was ignored or bypassed, or because of its failure to operate as designed, the dismantler may choose or be required to undertake second order event countermeasures. These would include, for example, use of personal protective equipment, application of fail-safe deployment procedures, or development of programs for work practices and training.

Personal protective equipment, including eye goggles and face shields, respirators, and protective clothing should be used by employees engaged in the deployment of air bag inflators. Fail-safe activation devices should be designed so that the air bag cannot inadvertently be actuated while the worker is attaching the deployment device to the inflator or its wiring harness. The design of such a fail-safe device will depend upon the selected deployment procedure; however, as an example, it might include a remote spring-loaded switch which requires a positive action safe-arm device on the part of the worker to activate the deployment device. This system would prevent

TABLE 2-2

POTENTIAL CHEMICAL HAZARDS IN MOTOR VEHICLES

SUBSTANCE	SOURCE IN MOTOR VEHICLES	EFFECT ON HUMANS
Carbon Monoxide CO	Vehicle exhaust or any incomplete combustion of organic material	Tissue hypoxia
Carbon Dioxide CO_2	Complete oxidation of organic material	Simple asphyxiant
Freon-12 $C\,Cl_2F_2$	Air conditioner fluid	Narcotic in high concentrations
Phosgene $COCL_2$	Decomposition product of Freon-12 at open flame	Decomposition to carbon monoxide and hydrochloric acid in the lungs. Severe exposure may be fatal
Fluorine Gas F_2	Decomposition product of Freon-12 at open flame	Corrosive to skin and mucous membranes. Long term disability (fluorosis) may develop
Oxides of Nitrogen NO_x	Vehicle exhaust	Respiratory irritant. Pulmonary edema may develop after severe exposure
Gasoline	Vehicle fuel system	Irritant and simple asphyxiant
Benzene C_6H_5	Minor constituent of vehicle fuel	Central nervous system depression. Chronic exposure may lead to depression of the hematopoietic system. Suspect leukemogen.
Lead Pb	Organic: Minor constituent of leaded vehicle fuel Inorganic: Battery	Gastrointestinal disturbances and anemia. Neuromuscular dysfunction may develop.
Sulfuric Acid H_2SO_4	Battery acid	Severe irritant for eyes, skin, and respiratory system
Hydrogen H_2	Gas evolution from battery	Simple asphyxiant

TABLE 2-2 POTENTIAL CHEMICAL HAZARDS IN MOTOR VEHICLES (Contd)

SUBSTANCE	SOURCE IN MOTOR VEHICLES	EFFECT ON HUMANS
Ethylene Glycol CH_2OHCH_2OH	Radiator Antifreeze	Central nervous system stimulation followed by depression. Kidney damage may result from chronic exposure.
Methanol CH_3OH	Windshield washer fluid	Narcotic and irritant. Chronic effects on the optic nerve.
Hydrochloric Acid HCl	Combustion of plastic material such as seats, rugs, interior panels	Severe irritant to eyes, skin, and respiratory system.
Asbestos	Brake pad linings	Pneumoconiosis (Asbestosis) and lung cancer
Mercury Hg	Mercury switches in hood and trunk	Respiratory and digestive disturbances. Chronic exposure may lead to neurologic and psychic disturbances.

Source: Arthur D. Little, Inc. estimates based upon available information.

a situation whereby a worker inadvertently attaches a live power source to the squib, causing immediate deployment and possible injury. This situation is avoided because the fail-safe design requires that the employee undertake additional operations which will place him at a location rather remote to the deployment site.

Work practices and training are considered as active countermeasures to protect employees during the event stage of air bag deployment. Workers in junkyards should be made aware of the potential hazards of air bags and should be trained to handle and deploy them in a safe manner. In those yards where customers are allowed to salvage parts for themselves, the yard management should take pains to ensure that they do not inadvertently deploy an air bag. Also, any potential environmental contamination should be carefully monitored with the appropriate clean-up provisions employed as necessary.

2.4 Post-Event Analysis

If prevention and minimization countermeasures either fail or are not properly employed at the dismantler yard, a third level of response or post-event countermeasure may be invoked. This third level of response is designed to minimize or reduce the unnecessary consequences of acute and chronic injury or environmental contamination. Typical third level responses include emergency medical treatment for trauma, medical surveillance programs to establish chronic health problems, and decontamination procedures to lessen environmental damage.

Pre-event and event countermeasures are intended to prevent injury or limit its severity; however, there is always a potential that severe injury will occur. In anticipation of such an event, dismantlers should be prepared to provide immediate emergency medical services. The dismantlers should be equipped to handle most minor first aid emergencies and should train their personnel in first aid techniques and cardiopulmonary resuscitation (CPR). Many states already require such activities, nevertheless, it is reasonable to assume that many of the smaller junkyards are not competent in this area.

Alternatively, dismantlers should be prepared to handle severe injuries or acute chemical exposures by having ready access to a local emergency medical unit (EMT). Although there is some variability between inidvidual jurisdictions, such services are typically available through fire or police departments or in conjunction with hospital emergency rooms. Regardless of the source, the emergency service should be made aware of the potential hazards at the junkyard and a system should be developed for immediate notification of the EMT in case of an emergency.

Concern has been expressed for the potential risk from chronic exposure to sodium azide. Much of this concern is based upon the unsubstantiated suspicion that sodium azide is a carcinogen. At the present time, there is no conclusive evidence that it exhibits such a property. However, the apparent risk, based upon the large number of potential exposures, warrants careful monitoring for the immediate future. To a large extent, the development of controlled deployment, protective equipment, and work practices will limit the problem of chronic exposure. The provisions should be supplemented by medical surveillance programs including periodic examination and special tests as necessary.

An essential aspect of any medical surveillance program involves periodic physical examinations. Although there is some debate as to the most efficient frequency for surveillance procedures, it is generally agreed that, where specific hazards are concerned, physical examinations can be useful for detecting early signs and symptoms of disease and for providing a stimulus for risk-reducing activities (e.g., stop smoking or job transfer). In some locations, it is not organizationally or economically feasible to support such a program; however, management can inform their employees and can recommend procedures for obtaining physical examinations on an individual basis.

It is common, for specific occupational hazards, to undertake special surveillance tests (e.g., urinary lead, pulmonary function, chest X-ray, sputum cytology). The relevance of such a program for junkyard workers is, at the present time, not under investigation;

however, if it appears that workers are indeed being exposed at levels which could be deleterious, it may deserve careful study in the future. As previously mentioned, such a program may be an organizational and economic burden for small employers.

Countermeasures, such as controlled deployment at the pre-event stage, will help to limit the extent and severity of environmental contamination. If it is assumed that some generant material will contaminate the environment, there are several procedures which should be adopted. In order to limit the amount of material which is allowed to contaminate the environment, consideration should be given for the development of monitoring systems. The simplest type of periodic monitoring involves visual inspection of the junkyard inventory to identify inflators which might be leaking material into the environment. Although this method is not precise, it is inexpensive and does not require the application of sophisticated techniques. Chemical monitoring would be required if it is necessary to track the fate of generant material in the environment. This type of monitoring might be conducted by use of continuous monitoring "sniffer" devices.

Continuous monitors have been utilized in some industries, especially for combustible vapors and gases, organic vapors such as vinyl chloride, and toxic gases such as carbon monoxide. Such an application does not appear to be warranted for monitoring of environmental contamination at junkyards, however, these may be used at shredder operations.

2.5 Countermeasure Analysis for Scrapyards

The majority of the automobile dismantlers retain a vehicle for 12 to 18 months. The vehicle hulk is then prepared for shipment to scrapyards where shredding, baling or shearing operations are employed to fragmentize the hulk. There are a variety of hazardous events which can occur as a result of the fragmentation of hulks containing non-deployed air bag inflators. These events, include acute and chronic health and safety hazards, contamination of residual fluff material, and contamination of ferrous and non-ferrous wash water. These individual hazards are displayed in Figure 2-3 and the countermeasure

techniques are displayed in Figure 2-4.

The various countermeasures proposed for the scrapyard operations are comparable in scope to those for the junkyard/dismantlers. The most important factor wich surfaces from an examination of Figure 2-4 is the recognition that controlled deployment of the air bag provides the most satisfactory approach to minimizing hazards. Controlled deployment could represent either a program at the scrapyards to deploy the air bags prior to processing or it could connote the receipt of vehicles from the dismantler, all of which have had the air bags removed or deployed. As with the junkyard/dismantler operations, it is evident that the application of event and post-event countermeasures are much less efficient in terms of insuring the safe handling and disposal of inflator modules.

2.6 NHTSA Involvement in Countermeasures

The preceeding analysis of countermeasure procedures provides an overview of the alternatives which must be considered when evaluating possible procedures to deploy retired air bag inflator modules. The focus of this evaluation was to provide to NHTSA information identifying the supplementary procedures which must be invoked if the deployment of air bag inflators enters into the event and post-event stages. It is obvious that the preferable mode for deployment would focus upon the pre-event stage and that the countermeasure requirements for the event and post-event periods are extremely difficult to implement, monitor and regulate at individual dismantler facilities. Also, in most situations, the event and post-event countermeasures expose the employee to potentially adverse effects from air bag handling and disposal. Therefore, from the perspective of insuring employee health and minimizing environmental pollution, the pre-event countermeasures offer the most attractive procedures to deploy air bag inflators(2). Also, the regulatory authority of NHTSA is most directly applicable to those various activities which are compatible with the pre-event countermeasures(3). Any efforts on the part of NHTSA to intervene or otherwise influence the event and post-event countermeasures would require the

involvement of other federal agencies including OSHA and EPA. NHTSA has the regulatory authority to specify the performance specification for the air bag system. To date, NHTSA has focused its attention upon specifications related to the deployment characteristics of the air bag. No recommendations have been made regarding the necessity for automotive manufacturers to incorporate into the air bag system hardware provisions which would expedite the safe deployment of the retired air bag. A future mandate from NHTSA to incorporate such hardware design changes, including modification to the squib system or the adaptation of a plug deployment connector into the air bag circuitry, are examples of pre-event countermeasures which could be initiated by DOT.

2.7 Summary

Dismantler/recyclers and scrapyard operations represent those two stages of the vehicle life cycle that are most amenable to implementing programs for the removal and deployment of retired air bag inflators. Alternatively, it is possible to implement a program for deployment which would involve private contractor operated facilities, but, this option ivolves the construction of new facilities and the development of an organizational structure which does not currently exist within most states. Clearly, there are many trade-offs involved in evaluating the feasible countermeasure options for deploying retired air bag inflator modules. This analysis proceeds by examining the available options for deployment and assessing their relative attractiveness in terms of several quantitative and qualitative scoring parameters.

REFERENCES AND SOURCES

SECTION 2.0

(1) Haddon, W. and Baker, S., Injury Control Preventive Medicine 2nd Edition, 1975

(2) Personal Communication with David Lambert, Executive Director, Automotive Occupant Protective Association, McLean, VA.

(3) Personal Communication with Clarence Ditlow III, Executive Director, Center for Auto Safety, Washington, D.C.

3. ALTERNATIVE APPROACHES TO THE SAFE HANDLING AND DISPOSAL OF RETIRED AIR BAG INFLATORS

3.1 Introduction

The goal of this program is to identify, evaluate, and suggest alternative programs which could be developed and implemented to assist in the safe handling and disposal of retired pyrotechnic air bag inflator modules. The proper design, evaluation, and implementation of such programs is crucial if the current procedures for dismantling and recycling of retired vehicles are to remain an effective mechanism for insuring the removal of junked vehicles from the automobile population.

There are several alternatives which should be considered for possible application to enhance the safe and effective handling of retired air bag inflators. Included among these are approaches based upon hardware modifications including a redesign of the inflator module; bounty or incentive systems based upon the premise that automobile dismantlers and other personnel in the scrap cycle should be compensated for the removal of the air bag inflator; fines, penalties, or other disincentives to encourage the vehicle owner to undertake the appropriate action to insure that the inflator module is removed from the vehicle prior to retirement; modifications to the current procedures for dismantling and recycling of motor vehicles including the shredding and baling operation; and the establishment of mandatory inspection and monitoring programs which include centralized facilities where, for a fee, air bag inflators would be removed, deployed or otherwise inactivated prior to retirement of the motor vehicle.

It is important to recognize that the successful deployment of a retired air bag inflator module requires the completion of two individual operations. These include the initial delivery of the vehicle to a dismantler/recycler, scrapyard, or deployment center followed by the activation of the inflator through one of several alternative hardware oriented procedures. It is widely acknowledged that tens of thousands of automobiles are abandoned annually. The success of any programs

to safely deploy retired inflator modules requires that the number of abandoned vehicles be minimized. Programs incorporating fines, bounties or periodic inspections may serve to increase the flow of retired vehicles into the recycling process, however, they appear to have little, if any, impact upon the safe handling of the retired inflator modules. This goal of safe deployment can be achieved through several approaches, one of which involves modifying the hardware designs of present inflator systems.

Once the vehicles are delivered to the deployment center, only then can the activiation of the air bag be completed through the application of a specific activation protocol. Therefore, it is important to first examine the life cycle of air bag equipped vehciles to determine the effectiveness of alternative programs which are designed to maximze the number of vehicles entering the recycling process. Then, given that the vehicle is delivered to a deployment center, analyses are conducted of the various hardware modifications which may be employed to assist in the safe handling and disposal of the air bag inflator. These modifications include procedures which are in some instances state of the art technology while others require that extensive research and development be undertaken.

Each of the individual approaches has positive and negative features which, when considered in total, can effect the overall feasibility of a specific deployment or removal approach. It is also possible, depending upon specific local or regional factors, for one particular program to be perfectly acceptable at one locale yet be less than desirable for implementation at another location. It appears that a crucial requirement for the successful implementation of any program includes the provision for uniformity of application across the U.S. This requirement necessitiates that various alternatives be evaulated in a semi-quantitative fashion to insure that the ultimate choice will be the most effective approach for implementation through the U.S.

There are several scoring or evaluation approaches which could be employed to evaluate the overall feasibility of the various options

which have been identified as potential candidates for insuring the safe handling and disposal of retired air bag inflators. Included among these are the traditional approaches, such as the Delphi method of forced decision making; elaborate multivariate statistical approaches such as factor or discriminent analysis; risk assessment techniques including failure mode and effect analysis or fault tree analysis; and elaborate performance scoring proceudres where system requirements are measured in terms of output or performance standards. The selection of the appropriate analytical tool requires careful consideration of several factors including identification of the input scoring parameters, an evaluation of the quality of data which are available to describe each parameter, the sensitivity of the output function to individual input parameters, and the degree of correlation between the individual parameters. The analytical rigor of the final scoring procedure should be based upon a recognition of the limitations upon input data and the output format should retain sufficient flexibility to be amenable to reasonable interpretation.

3.2 Input Parameters

There are a wide variety of input parameters which can be applied to rank order the alternative approaches or procedures for insuring the safe handling and disposal of retired air bag inflators. Several of these paramters will be quantitative in nature and include, for example, costs and population at risk. Others are less amenable to quantification and include consideration for system reliability, technical feasibility, and probability for success. Each of these individual parameters is discussed below to identify the crucial considerations which enter into the individual scoring procedure.

3.2.1 Costs

The costs for the implementation of a particular program include consideration for research and development costs, capital costs, operating and maintenance costs, as well as costs associated with the initiation of inspection or other surveillance programs which are necessary to monitor the success of a particular deployment program.

An example of typical costs would be those associated with the development, installation, and actuation of a specially designed electro explosive device (squib) to assist in deploying retired air bag inflators. This new squib must be designed, developed and placed into production. All testing and associated costs are assigned to the current program. Also, a special tirggering device must be supplied to each individual scrapyard or other deployment location to provide the energy source necessary to activate the squib. The cost of these devices including any provisions for special housing, storage or maintenance, are assigned to this program. Worker training costs must also be acknowledged and allocated accordingly. Finally, the requirements to properly police the deployment activity (to insure that the initiator is not stolen or otherwise improperly used) must also enter into the cost calculations.

There are a wide variety of costs which may be anticipated and accounted for either directly or indirectly. Unfortunately, many costs are not well documented, and in most instnaces, can only be approximated based upon a relationship to analogous situations. Therefore, in the absence of documented cost information, the various costs for a particular deployment strategy may be identified as high, moderate, or low to categorize not only the costs for a particular system, but also to provide a basis for comparing analogous costs (e.g., research and development for two competing options) for two different deployment strategies.

It is also important to acknowledge the proper allocation of costs among the various sectors which are involved in the life cycle of the air bag inflator module. These participants include the manufacturers of the inflators, the automobile manufacturers who purchase certain components of the air bag system from specific vendors; the original purchasers and subsequent owners if the car is resold; dismantlers; owners and operators of shredders, shearers, flatteners, balers; state, federal, and local governments; and the owners or proprietors of facilities engaged in the recycling or reclamation of residual materials from the processing of retired passenger motor vehicles.

The adoption of a specific deployment strategy can cause the associated cost to vary widely both in terms of their level and the manner in which they are allocated amongst the various sectors. In many instances, it may be important to recognize that costs can have severe localized impacts upon particular sectors which can disrupt market structure and cause the occurrence of severe localized dislocations.

There are several questions which must be raised regarding how these individual costs will be apportioned or otherwise distributed amongst the various participants in the air bag inflator life-cycle. Specific issues relate to whether the consumer or the producer should bear the costs for insuring the safe handling and disposal of the retired inflator modules. One line of reasoning would propose that the consumer receives the benefits of the passive restraint system, and therefore, should bear the costs. Alternatively, the manufacturers have selected sodium azide as the pyrotechnic generant; and given the toxic properties of the chemical, scrapyard personnel are reluctant to handle azide; therefore, any costs associated with the safe disposal of azide should fall upon the manufactureres who have selected the material as a gas generant. In contrast, it could be argued that scrapyard dealers or automobile recyclers achieve their livelihood from processing of retired vehicles, and therefore, should be prepared to bare any economic burdens associated with safe handling of the air bag inflator. If they are not prepared to absorb these costs, then they can restrict their entrepreneurial endeavors to those vehicles which are not equipped with air bag restraint systems.

Any allocation of costs associated with bounties or fines to discourage improper handling of the inflators would most logically be incorporated into current programs for vehicle inspection, title law coverage or analogous enforcement or monitoring activities. In the absence of any pre-existing programs, these costs should be carefully examined to assess the trade-offs between governmental programs versus those conducted by private contractors. The life cycle costs for a

particular regulatory program may be better controlled through the use of private contractors, but the performance of such contractors will require the institution of a program to properly police the operation of the contractors.

3.2.2 Risk

This parameter represents the assessment of risk to those individuals whose interaction with the air bag inflator life cycle can be influenced by the implimentation of a particular policy, program or procedure which has been invoked to expedite the disposal of retired non-deployed inflator modules. For example, if the air bag inflator module is redesigned to incorporate a device to expedite deployment, then the overall reliability of the air bag system may become compromised in terms of the number of potential inadvertant deployments. These inadvertant deployments could affect (place at increased risk) a specific population including the vehicle owner and his passengers, automotive repair and service personnel, and scrapyard workers who will interact with the air bag module. Each of these groups will be confronted with a somewhat increased risk associated with inadvertant deployment of the air bag which is somewhat greater than the risk which would occur in the absence of any procedures for hardware modification.

The population at risk for the entire life cycle of the air bag restraint system is understood to include the following:

a. Employees who manufacture, ship or assemble air bags.

b. The owner (either original or subsequent) of the air bag equipped vehicle.

c. Automobile service personnel including both dealers and independent service stations.

d. Scrapyard or automobile dismantler personnel.

e. Personnel involved with automobile shredding, baling, and flattening operations.

f. Personnel required to handle or process the various waste streams which derive from recycling of retired automobiles including ferrous and non-ferrous metallic wastes, fluff and other residues.

The identification and allocation of risk is important to properly identify and interpret the impacts of various deployment strategies upon all participants in the automobile life cycle. Any decisions which are made regarding various optional deployment strategies must clearly acknowledge the existence of any impacts or risks upon other participants in the automobile recycling process.

3.2.3 Technical Feasibility

Technical feasibility relates to the availability of hardware equipment, or other operational entities, such as bounty systems or inspection programs, to provide the necessary capability to insure the safe handling and deployment of discarded air bag inflator modules. A hardware based system is judged to be technically viable or feasible when the equipment or device required to implement a program is readily available and can be essentially purchased "off the shelf" and provided to manufacturers or others involved in the air bag deployment program. Equipment which is still in the research and development stage or which is available in limited quantities, is not judged to provide a technically feasible solution to the problem or hardware modification.

Feasibility also relates to the functional status of a particular regulatory or political structure such as a state mandated motor vehicle safety or emission control inspection program which could provide the basic foundation from which to implement air bag monitoring and control programs. The presence of an existing organizational structure which can support a particular type of activity is crucial to the achievement of feasibility for a given undertaking. In the absence of a pre-existing organization, the extended lead time required to develop such structure, fund and staff the operation as necessary, and develop and implement programs and procedures, could effectively nullify the feasibility of a particular regulatory approach.

The concept of lead-time is crucial to the evaluation of technical feasibility. There is a very short available time frame involved with implimentation of certain hardware based deployment options (e.g., modification to air bag design) because the automotive industry is currently selecting their vendors for individual pieces of hardware. Alternatively, other programs such as incentive bounty systems can have a somewhat longer lead time frame prior to implementation because they do not involve decisions related to hardware designs. Also, the presence of state motor vehicle inspection programs or the existence of title laws for vehicular ownership would reduce the lead time requirements, and therefore, improve the feasibility for certain types of regulatory programs based upon principles of monitoring or inspection.

Feasibility further relates to whether the intended deployment procedure can be invoked solely through the auspices of NHTSA or whether interagency agreements are required to institute, impliment and monitor a selected program. Consider the application of a radio frequency source (with a coded signal) to deploy inflator modules at scrapyards. This device may currently be available but its design was not intended for use in scrapyards. There may be requirements for Federal Communication Commission (FCC) authorization for use of the device and licensing of the individual scrapyard employers to own and operate the RF source. Alternatively, the application of certain "kill solutions" to neutralize sodium azide or other generant chemicals released into the shredder process water may require an EPA discharge permit if these waters are released into sanitary or storm sewers. Similiar scenarios related to DOT regulations for poisonous or explosive materials could be envisioned as affecting the development of new chemical generant aterials. Sodium azide has generally been adopted as an acceptable gas generant, but the selection of an alternative pyrotechnic may require the initiation of a new round of licensing and testing which could be time consuming and substantially delay the introduction of a new pyrotechnic inflator.

The issues of technical feasibility are defined as relating only to the implementation of an individual deployment procedure and are

not reflective of the impact of said program upon the current operations which comprise the life cycle of an automobile air bag inflator.

3.2.4 System Reliability

It is important that any procedures employed to assist in the safe and effective deployment of retired air bag inflator modules not compromise the reliability of the passive restraint system with respect to minimizing inadvertant deployment of the air bag during normal use conditions. The overriding concern of the motor vehcile manufacturers is to insure that the passive restraint system have the highest achieveable levels with respect to reliability. This implies that extreme efforts are employed to insure the readiness of the system during any potential collision conditions while simultaneously minimizing the probability for inadvertant deployment resulting from a mechanical, electrical or other stimulus not directly associated with the normal deployment mode. Any system hardware modifications which interact with the current design configurations are suspected of compromising the safety provisions (filters, sensors, receivers) which the industry has incorporated into their present designs. Therefore, there is a strong tendency for the automotive industry to resist rigorously any suggestion that current air bag inflator designs be modified to incorporate hardware devices which might assist in the safe and effective deployeemnt of retired or obsolete air bag inflator modules.

It is obvious that the introduction of any device into the air bag circuitry will compromise the reliability of the original system. No device is 100% reliable and simple probability theory will identify the degree to which existing system reliability is effected by the addition of another component which has a reliability of less than 100 percent. Therefore, it is possible to appreciate that any modification to the design of the air bag system to ease the deployment of the retired inflator will also compromise the reliability of the air bag during normal use. Unfortunately, there are few available reliability data for the various components which comprise the air bag restraint system. It is possible to locate certain types of reliability data for

individual components of the air bag restraint system (squibs, capacitors, solder joints, inertial detectors), based upon data derived from military hardware applications. It is not possible to speculate regarding the reliability of the individual air bag components relative to the performance history recorded for comparable devices under military use applications. However, a review of the reported military data indicates that even modest changes in the manufacturers designs for the air bag system will reduce the overall reliability.

These reductions in reliability are not readily translated to measurable increases in the number of inadvertent deployments and the possible fatalities or injuries which might result. There could be literally millions of individuals exposed to air bag restraint systems under normal use conditions and any reduction in the reliability of the system as it is currently configured could have marked effects upon the consumer population in terms of the number of potential inadvertent deployments during normal use conditions. It is important to insure that any considerations toward modification of the air bag system design be accompanied by an analysis of the associated reduction in system reliability and its impact (if any) upon the consumer population. The overall effectiveness and attractiveness of the air bag restraint system has been the subject of some debate, and it is important to insure that any possibility for inadvertent deployment (and the associated issues of reliability) be maintained at a minimum level.

3.2.5 Impact Upon Current Operations

The introduction of a program to insure the safe handling and disposal of retired air bag inflator modules can have impacts upon the manner in which existing operations are conducted within the various stages of the vehicle life cycle. The disruption or interference with standard operating procedures for handling retired motor vehicles should be a major consideration when evaluating alternative air bag deployment programs. The recycling of motor vehicle parts and ferrous and non-ferrous scrap represents a major commercial venture whose efficiency and standard operating procedures could be impacted by programs designed to remove air bag inflators from retired motor vehicles.

Automobile dismantlers and recyclers are involved in the recycling of used automobile parts and their operations could be markedly effected by the requirements to inspect incoming vehciles to ascertain the presence of the air bag; to remove or deploy the bag and then to provide storage facilities for those inflators which are removed and not deployed [(1)]. Any storage or stockpiling may require provisions for establishing a secure area to prevent theft or vandalism. The requirements to inspect incoming vehicles, deploy air bags, train personnel, and handle special deployment equipment is within the capabilities of most dismantler/recycler operations but could pose economic burdens upon many of the smaller marginal operators in this industry.

Completion of the dismantling process is followed by transfer of the vehicle hulk to scrap processers where the operations such as shredding, baling or shearing are utilized to reduce the vehicle into fragments suitable for raw material feed to metal foundry operations. The current trends within this industry are toward both increased automation and throughput of vehicle hulks to conserve both energy and reduce the cost of labor [(2)]. The requirements for scrapyard operators to monitor their raw material feed to ascertain the presence or absence of an inflator will be counterproductive to the goals of increased productivity[(3),(4)]. Furthermore, if scrapyard operators handled non-deployed inflators, then they must be prepared to utilize various techniques such as application of kill solutions to neutralize azide in processing water. Also, there may be a necessity for the scrapyard operators to obtain EPA discharge permits prior to the release of process water or by-product fluff contaminated with azide.

Other participants in the scrap cycle also play significant roles in the recycling of retired vehicles, but their influence upon the overall productivity of recycling is clearly secondary to the dismantlers and the scrapyard operators. The automobile manufacturers or their vendors can enhance the safe handling of air bag inflators primarily through the modification of existing hardware designs to ease the deployment of the retired air bag. However, the responsibility for the ultimate deployment of a hardware device rests at either the automobile

dismantler, scrapyard or designated deployment center. The automobile consumer can affect the safe handling of air bags only if the bounty or penalty system requires that the final owner properly deliver the vehicle to the designated deployment location which would, in most situations, be a dismantler or scrap recycler. Therefore, the vehicle owner acts only as an intermediary to deliver the retired vehicle to a designated deployment facility.

The operators of electric arc furnaces or foundry melting operations play secondary roles in the safe handling and disposal of air bag inflators. The nautre of the automobile recycling process which involves the initial removal of saleable parts and a subsequent fragmentation of the hulk prior to furnace melting operations suggests that any active programs to insure the safe handling and disposal of air bag inflators should precede the furnace melting operations. Therefore, it is not anticipated that metal melt operations will ever rise to a position of prominence with respect to the safe handling and disposal of air bag inflators.

In conclusion, based upon a review of the automobile recycling process and its involvement with the safe handling and disposal of retired air bag inflator modules, the automobile dismantlers and the scrapyard operators should play major roles in any programs which are developed and implemented to achieve the safe handling and disposal of retired air bag inflator modules. These individuals have extensive experience in handling retired motor vehicles and are familiar with hazards such as gasoline tanks, shock absorbers, impact bumpers, battery acid, high pressure air conditioning systems, and other corrosive or explosive fluids. The attempts to transfer these responsibilities to other sectors such as private contractors could be successful, but there would be anticipated start-up delays or other problems related to implementation.

3.2.6 Probability for Compliance Achievement

This reflects a consideration for two factors which relate to the potential for overall success of a particular air bag deployment

methodology. The first factor addresses the degree to which an individual deployment device or procedure will be acceptable, and therefore, implemented by personnel involved in the automobile scrap cycle. In other words, how rigorously will a specified deployment protocol be followed by personnel responsible for deploying retired air bags. The second factor relates to assessing the overall effectiveness of a particular procedure in achieving the desired goal of air bag deployment. That is, given that a specified work procedure is initiated, what is the probability that it will succeed in insuring deployment of the retired air bag inflator module. Therefore, the achievement of a high level of overall compliance requires that a high proportion of the personnel involved in the automobile recycling process employ an effective device to deploy air bags. If either the level of utilization or the effectiveness of the device is decreased, then the overall level of compliance achievement is compromised.

There are obviously some trade-offs between the rate of utilization, level of effectiveness and the overall achievement of a high degree of compliance. Certain deployment approaches may be very simplistic, not requiring a high degree of worker sophistication, and therefore, experience a high rate of utilization. However, the simplistic nature of the device may compromise its effectiveness such that even though the rate of utilization is high, the overall probability of compliance achievement is only moderate. Alternatively, a more complicated deployment procedure which is highly effective may require that personnel undertake an additional level of effort which they are not always prepared to offer. Therefore, although the device is highly effective, poor worker performance related to the rate of utilization compromises the level of compliance which is ultimately achieved.

Communication with individuals involved within the Automobile Dismantling and Recycling Association (ADRA) indicate that there is some concern regarding the handling of inflators at the various dismantling locations throughout the U.S.[5]. The preferred mechanisms for handling of retired inflators within this segment of the industry involve either remote deployment or removal of the intact inflator with

intermediate on-site storage and subsequent shipment to a centralized collection location. Although, some dismantlers and recyclers are knowledgable regarding the potential problems associated with the introduction of air bag systems, the dismantler population, in general, has not established a concensus regarding firstly the degree of hazard associated with the inflator, and secondly what the preferred approach would be for handling the hazard. ADRA has been attempting to inform and educate its membership regarding the potential problems associated with handling of retired inflator modules. However, several factors, including the recent decision by the automobile industry to select pyrotechnic versus hybrid designs, have served to reduce the rate at which information has been distributed to the ADRA membership. ADRA has made at least one submittal to NHTSA regarding a possible procedure for deploying the retired inflator modules[6]. This includes the recommendation for the remote deployment of the inflator module through utilization of a 12 volt d.c. source attached directly to the leads of the inflator.

Vehicles which are processed by dismantlers and recyclers are transferred to scrap recyclers (shredders, balers, shearers) for further recycling into metallic scrap materials for raw material feed to metal melt operations. A larger majority of the hulks, which are discarded, will be delivered to shredder operations. Conversations with individual shredder owners and operators indicate that there would be few anticipated problems associated with the safe handling of non-deployed inflators in retired hulks. The available testing data substantiate that upwards of 85% of the air bag inflators fed into an automobile shredder are either deployed or fractured during the shredding process[7]. Air bag deployment does not appear to be of sufficient severity to damage the internal structure of the shredder. Current designs include explosion suppression systemsand the use of blow-out panelscould further insure that the potential impacts of explosions are minimized. Other concerns, regarding the safe handling of pyrotechnic inflators, relate to potential accumulations of azide within processing equipment when inflators are fragmented but not deployed

during the shredding process. Such accumulations of azide can lead to formation of copper or lead azide, both of which are powerful explosives. However, the instability of these two compounds should effectively serve as a self-limiting process to retard the excessive formation of lead or copper azide prior to detonation.

The ferrous and non-ferrous by-products from the shredding process are transferred to metal reclamation processes. These processes involve metal melting operations for the manufacture of steel, copper, aluminum, zinc and other metallics. The accumulation of azide in the ferrous fraction would primarily be related to either the entrapment of azide in partially fragmented inflators or the total encapsualtion of azide in those inflators which exit the shredding operation intact. Concerns for adverse effects relate to personnel handling azide contaminated scrap as well as the possibility that azide charged into metal melt furnaces will explode and propell either molten metal or scrap metal contents from the furnace.

The available information suggests that the risk associated with an explosive eruption within a metal melt furnace following the charging of scrap containing azide is inversly proportional to overall furnace capacity and the level of automation associated with the charging process. At this juncture, there do not appear to be any requirements for immediate remedial procedures to protect the health and safety of personnel involved in the handling of either ferrous or non-ferrous scrap at furnace melting foundries. Any potential exposure problems with manual sorting or pre-processing of scrap can be adequately addressed through the application of personal protective equipment. Alternatively, automation of the material handling procedures will remove the major route of exposure by which workers may contact sodium azide or its derivative azide compounds.

In conclusion, the effectiveness of a particular deployment methodology depends upon several factors including the stage of the vehicle life cycle where deployment is initiated, the level of personal interaction required to cause deployment, the incentives or disincentives to

participate in the deployment operations, the familiarity of the operator with the required deployment procedures, and an appreciation for the implications associated with improperly handling the retired inflator module.

3.2.7 Results

It is apparent that hardware modifications can provide one approach to expediting the deployment of retired inflator modules. NHTSA has expressed interest regarding the development of various devices which could be incorporated into the design of air bag inflator systems to expedite this deployment. A preliminary step in the development process requires a careful evaluation of current and proposed technology to identify and evaluate the viable alternatives which are compatable with the goals for safe handling and disposal of retired inflator modules.

There are many categories of deployment devices which could be extremely effective in terms of deploying retired air bag inflators. High energy sources (lasers, microwaves, UV) which access the inflator through an optical window are examples of an effective device. The use of the electronic lock which transmits both a coded signal and an energy source provides a very acceptable deployment device. However, there are many concerns regarding the advisability of deploying these type devices at poorly policed locations, such as dismantling facilities. Available information substantiates that the most effective deployment devices may require a high level of employee sophistication with respect to operational procedures. This required level of sophistication may not be available at existing dismantler operations unless procedures are implemented to train personnel regarding the procedures necessary to safely handle and deploy retired air bag inflator modules.

This analysis proceeds by examining in detail the specific hardware modifications that would be required to implement the proposed deployment program. A series of altnerative deployment devices are identified and evaluated relative to a series of performance criteria.

Further attention is also directed at examining, in a preliminary nature, the possible effectiveness of different approaches to simultaneously reduce the prevalence and incidence of abandoned automobiles to insure that the number of non-deployed air bag inflators within the environment is maintained at a minimal level.

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SECTION 3.0

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4. HARDWARE DESIGNS FOR AIR BAG RESTRAINT SYSTEMS

4.1 Introduction

The current designs for air bag restraint systems for use in 1981 model year vehicles are based upon the application of pyrotechnic gas generants. The gas generant used in these inflators is sodium azide, which, upon combustion, results in the production of nitrogen gas. Current air bag designs are the result of thorough testing and evaluation and represent an industry position that system reliability is of primary importance in insuring the successful incorporation of air bag restraints as an essential safety component of the U.S. passenger car.

4.2 Generic Designs for Air Bag Systems

It is possible to modify the design configuration of air bag systems such that they will be compatible with procedures to remotely deploy the air bag during the initial stages of the vehicle salvage cycle. However, there is some uncertainty regarding the exact hardware configurations which will be adopted by automobile manufacturers and as such an assessment was made of the system configuration which will be utilized on a trial basis (as optional equipment) in 1981 model large size passenger vehicles.

The generic design of air bag restraint systems would include many of the following components:

- Crash Sensing Mechanism
- Power Supply Backup
- System Diagnostics
- Crash Monitoring and Failure Recorder
- Inflator Module

4.2.1 Crash Sensing Mechanism

The crash sensing mechanism generally consists of a sensor package, with one grouping mounted in the forward portion (bumper, radiator or hood area) of the vehicle, while the second package is mounted adjacent

to the cowl or passenger compartment. These packages operate upon different principles with the forward unit based upon a velocity change calibration while the rear unit may be activated by a change in acceleration and the resulting gravity or g-forces which are generated.

It appears that there are few options which could be employed to modify the individual detectors to expedite the deployment of retired inflators while simultaneously insuring that the reliability of the system is maintained. These units are carefully calibrated based upon the "crash characterisitics" of individual vehicles and redesign of the detector requires manufactureres to re-evaluate and re-think the entire question of sensor specification. Furthermore, there is insufficient time available to redesign the detector system for introduction in 1982, and even if the detectors are modified, the actuation of these devices to ease deployment requires that the air bag wiring harness be intact and this condition cannot be guaranteed for a majority of the vehicles entering scrapyards. Also, individual manufacturers are using different sensor designs which are not amenable to a common deployment mode.

In conclusion, there are several factors related to lead time, system reliability, and preferential deployment procedures which suggest that modification of sensor design may not provide the most practical approach for the safe deployment of retired air bag inflators.

4.2.2 System Diagnostics

The diagnostics for the air bag restraint system are designed to serve several functions including the primary function of transmitting a signal to the driver establishing the ready condition of the air bag system. There are several types of potential malfunctions which may be diagnosed by the system and these include:

- shorted or closed detector
- low or lost system power
- open circuitry
- diagnostic failures

- warning lamp failure
- fuse or open circuitry

The system diagnostics are sophisticated electronic devices which have been designed to identify and respond to the myriad of possible failure modes which could involve the air bag inflator module. The goal of the automotive manufacturers is to improve the reliability of the air bag system and they have continued to focus upon the diagnostics as a key component of the overall system. Therefore, based upon concerns for reduced reliability and the limited time frame available prior to the 1982 introduction, it does not appear viable to alter the diagnostic system to aid deployment or disposal of retired air bag inflator modules.

4.2.3 Crash Monitoring and Failure Recording

The crash monitoring and failure recording device is primarily designed to facilitate a rev w of the sequence of events prior to deployment of the inflator module during crash conditions. The recorder may also establish the period of time, if any, that the vehicle was operated with a malfunctioning air bag system. A series of detectors, fuses, and actuation recorders are built into the system which respond to the crash conditions of the vehicle. Upon actuation, the detectors serve to "blow the fuse" which then transmits power to a second fuse which is calibrated to blow depending upon whether or not the air bag deploys. The detectors are calibrated to span the anticipated "operating range" for the air bag and when coupled with the actuation recorder provide the basis for establishing a "record" of when and whether the inflator module was deployed properly.

There is a possibility that not all automobile manufacturers will incorporate recorders into their air bag inflator systems. Several questions remain surrounding the efficacy or reliability of the recorders and whether they are immune from tampering or whether they can be retrieved following an accident situation. Given that recorders may not be universally incorporated into the air bag equipped passenger vehicles, and that they are subject to tampering or other problems,

indications are that these devices should not be modified to increase the effectiveness with which retired air bag inflators are deployed.

4.2.4 Inflator Module

The pyrotechnic inflator module consists of a sturdy steel cylindrical housing containing a pelletized mixture of sodium azide and an oxidizing agent that is hermetically sealed. The pyrotechnic pellets are actuated through the stimulus from an electric match or squib which is ignited by a d.c. electric signal. The generant gas passes through a series of filters, baffles and diffusers prior to entering the air bag. Given that the gas generation in the air bag deployment process is initiated through the stimulus of the squib, it appears appropriate that the squib be selected as that individual component within the inflator which can be most easily altered to selectively modify the deployment characteristics of the air bag unit. The degree of design modification necessary to develop a new squib depends upon the nature and extent of the external stimulus which will be incorporated into the deployment process for retired air bag inflators. The direct application of a d.c. source would require virtually no change in the design of the squib. Alternatively, the implementation of more exotic deployment stimuli including ultra sound, coded radio frequencies, or high energy sources could necessitate marked changes in the design characteristics of the squib. Consideration must also be given to insure that proper filtering devices are utilized to remove random extermal stimuli which if encountered during normal use could cause inadvertent deployment of the air bag. Coded or frequency tuned squibs would also provide the basis for which to more closely specify the tolerances on the signal which would be utilized to deploy the retired air bag inflators. Finally, a combination of filters and signal coded or tuned squibs connected in series would provide the most assurance that the inflator is responsive to a special deployment device while simultaneoulsy providing reliable performance during normal operation conditions.

This brief review of the various operating components within the

air bag inflator system suggests that any hardware modification to ease the deployment of retired non-deployed inflators should focus upon the inflator module including the squib. One feasible alternative would involve retaining the present design and simply modifying the external circuitry to incorporate a plug connector or other device to assist in deployment through direct application of a d.c. source. This procedure would remove any requirements to modify the squib design and would, therefore, not impact the critical lead time necessary for manufacturers to develop, test, and evaluate new squib configurations. However, the integration of any external adapter or connector into the air bag circuitry will also enhance the probability that unauthorized personnel including vandals, the vehicle owner, and automotive service personnel could advertently or inadvertently deploy the system. Therefore, the various trade-offs between technical feasibility, development costs, ease of deployment, population at risk, and probability of success, must be evaluated to insure that the most safe and effective system is developed for deployment.

4.3 Specific System Designs

The automobile industry is currently considering two basic design configurations for the air bag restraint systems which will be available as optional equipment on certain large model 1981 passenger cars. These competing designs are comprised of somewhat similar components, but differ with respect to the wiring configurations, number of detectors, and their locations within the vehicle, procedures for energizing the system, use of diagnostic recorders, and system compatibility with procedures to promote deployment of obsolete or retired systems early in the vehicle salvage cycle. See Figure 4-1.

The air bag configurations for the two competing designs are based upon black box representations consisting of a detector system, wiring harness including the recorder (if any) and system diagnostics, and the inflator modules. The individual sensing systems are based upon comparable operating principles with the front sensor which is mounted in the bumper area operating upon an inertial principle while the rear

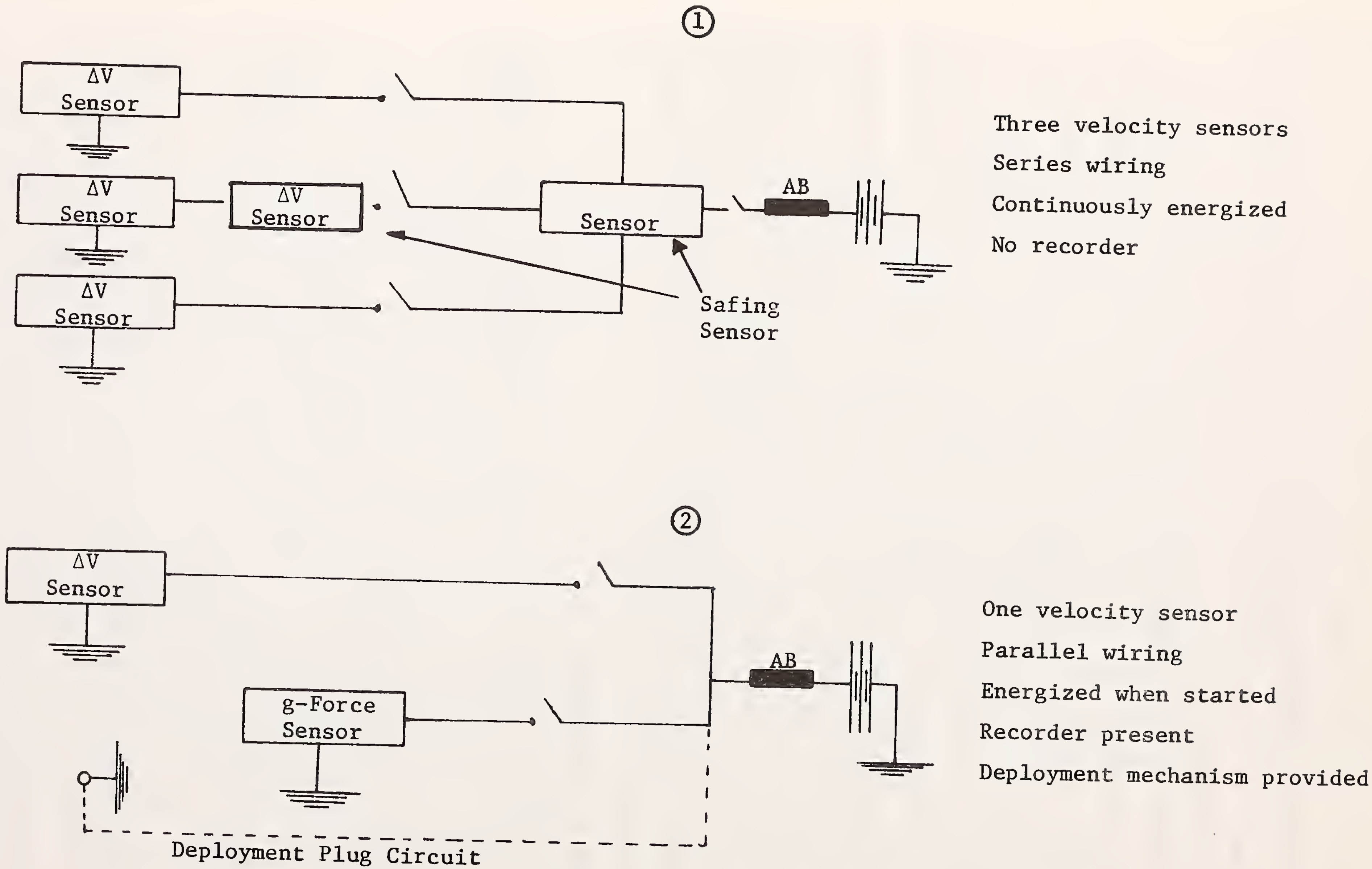


Figure 4-1

ALTERNATIVE AIR BAG CIRCUITS

Source: Arthur D. Little, Inc. estimates based upon available information.

sensor, mounted on the cowl, is dependent upon actuation by a predetermined level of gravity (g) force. The number of inertial sensors (quick detection/slow response) is subject to variation, but the system must be capable of responding to crash impacts which span the 30° angle represented by the area between the ten o'clock and two o'clock crash positions. The secondary sensor which is a slow detection/quick response device is mounted on the cowl and may be placed in either a series or parallel mode with the inertial sensor.

The first design configuration based upon a series wiring of the gas damped or viscous flow sensors incorporates three forward units mounted in the front of the vehicle to detect wide angle and direct impacts[(1)]. One of these sensors must fire and transmit a signal to the second cowl sensor (safing sensor) before the air bag will activate. If the second sensor does not activate, then the air bag will not deploy. The concept of the safing sensor is designed to prevent inadvertent deployments associated with events such as bottoming out which would cause momentary high g-forces but are not of sufficient severity to justify deployment of the air bag.

The second design alternative is based upon a parallel wiring configuration and incorporates a single inertial sensor in combination with a g-force cowl sensor[(2)]. The cowl sensor performs a dual role of detecting both g-forces associated with events such as ride-up onto guardrails and also wide angle crashes which impact the A pillar or frame of the car. The parallel design was based upon an evaluation of historical accident data for air bag equipped vehicles which indicate that there are certain classes of accidents which require deployment of air bag, but which for one or another reason do not cause both sensors to activate.

There are conflicting reports regarding the merits of individual wiring configurations. It is sufficient, at this point, to assume that the selection of an individual wiring approach reflects the results of testing data which, in some cases, are proprietory and are not readily available for independent review and evaluation.

There are two schools of thought regarding the most desirable manner by which to energize the air bag system. The first approach employs a design which energizes the system upon actuating the ignition key, while the alternative design is continually energized independent of the key position.

Diagnostic crash recorders may not be included in both competing designs. The choice not to include the detector is supported by performance achievements based upon extensive research and development programs[4]. Finally, one system may include a separate deployment circuit whereby a plug connector can be used to remotely deploy the inflator module.

In conclusion, there are several apparent differences regarding the hardware configurations and operating procedures for the air bag systems which are slated for introduction in 1981. These differences may effect the relative ease with which the air bag inflator may be deployed. It is not possible, based upon existing information, to identify whether either design is more amenable to safe handling and deployment during the disposal process. There is some indication that the squibs used in both devices are comparable with respect to shielding and other considerations. Therefore, the following recommendations for deployment procedures are equally amenable for either of the 1981 proposed designs.

4.4 Deployment of Air Bag Inflators Through External Stimuli

The deployment of retired air bag inflators during the initial stages of the automobile recycling process will involve consideration for the use of electrical (d.c.), thermal, mechanical, or radio frequency stimuli to cause firing of the squib. The following section addresses in detail the feasibility of employing alternative deployment devices.

4.4.1 Electrical Deployment

The electrical deployment of retired or obsolete air bag inflator modules is defined as the application of a direct current (d.c.) source to the leads of the inflator such that the bridge wire of the electro-explosive device (EED) becomes heated and initiates the combustion of

the pyrotechnic gas generant. The effective application of direct current to the inflator can be conducted by accessing the leads through a plug connector which is installed as an integral part of the air bag system. This plug could be located either at the front bumper area or on the passenger compartment wall of the vehicle[5]. There are obvious requirements that the wiring system of the air bag retain its integrity such that the d.c. current can be transmitted uninterruptedly to the squib.

The application of the d.c. stimulus requires that any detector in the circuit either be bypassed, or actuated to insure that all switches are closed and the electrical circuit is completed. It appears that the most expedient means for deployment would encompass a plug connector which when connected to the dc source bypasses the detector and diagnostic circuit and is wired directly to the leads of the EED. This would insure that any malfunction of the detector (following the application of mechanical energy to close the circuit) would not preclude deployment of the retired air bag inflator. The attachment of the electrical lead to a plug mounted on the bumper or radiator would provide a means for remotely deploying the air bag (provided the wiring has retained its integrity) and would minimize the potential risk of injury caused by employees being struck by metal or glass fragments contained within the vehicle which became airborne do to the forces generated during the deployment operation.

The positioning of the plug connector at an accessible location on the radiator exposes the air bag system to overt action by vandals and inquisitive owners whose actions could also deploy or otherwise compromise the effectiveness of the air bag system. There are several precautions which could be invoked to insure that any unauthorized deployments are minimized. These may include the design of a connector whose physical configuration would necessitate that a specially (industry provided) designed connector be used to activate the circuit. Other security provisions would relate to enclosing the connector in a tamper-proof housing, design of protective grounding requirements, or installation of protective switches which must be activated prior to

energizing the system.

The obvious merits of this type of dc deployment relate to the modest equipment requirements (12 volt battery, cable leads, plug connector) and minimum level of training required for personnel responsible for deploying the air bag. Alternatively, if the deployment device is made too accessible, then it will become the target for vandals and other uninformed tinkerers such that many air bags will be maliciously deployed prior to their reaching an obsolete or retired condition.

The automotive industry has undertaken many programs designed to minimize the number of inadvertent deployments of air bag inflator modules and there is some resistence to modifying system designs if reliability under normal use conditions is compromised. Therefore, although the installation of the connector plug is trivial, and its activation relatively simple, the insertion of this device into the air bag circuitry does serve to compromise the effectiveness of the air bag relative to its performance in the absence of the plug connector. Some manufacturers would prefer to retain the system in its present configuration and deploy or otherwise deactivate the air bag via means other than by application of dc current through a plug connector which is wired directly into the air bag circuitry[6].

4.4.2 Electromagnetic Radiation/Radio Frequency

The second alternative method for deployment of obsolete inflators would involve the application of frequency and energy specific electromagnetic radiation to energize the EED and cause combustion of the pyrotechnic material[7]. There is some uncertainty regarding the level of energy which would be required to activate the squib and the susceptibility of the system to radio frequency or audio frequency voltage depends not only upon the design of the EED but also several factors related to the physical and operating condition of the motor vehicle which contains the inflator module. For example, the configuration of the wiring harness, including location of grounds can have an impact upon the strength of the RF signal received by the EED. Also, other

features of the automobile which impact its RF susceptibility include:

- power door latches
- emergency flashers
- air conditioners
- power windows
- CB radio
- windshield wipers
- defrosters
- other electrical components

The presence of these accessories was acknowledged during the design of the air bag system and provisions were undertaken to insure the proper shielding of this equipment in an environment where radio frequencies could generate a signal capable of inadvertently deploying the air bag. Typical environments where there may be high levels of electromagnetic radiation include transmitting antennae associated with radio and television transmission, radar sites such as airports, amateur equipment including shortwave systems; industrialized locations with activities related to arc welding, electric furnaces and induction heating; and finally, high voltage power transmission lines.

4.4.2.1 EED Actuation/Failure

The available information indicates that the military has sponsored extensive programs to evaluate the susceptibility of EED's to electromagnetic radiation. There are several possible modes by which energy extracted from the ambient environment can cause the EED to activate. These include the concepts of pin-to-pin arcing, pin-to-case arcing, and bridgewire-to-bridgewire arcing. Pin-to-pin refers to the receipt of energy by the bridgewire spanning the two pins, subsequent heating and activation of the EED. Pin-to-case is exemplified by the situation where the dielectric material degrades and arcing occurs between the pin and case. Bridgewire-to-bridgewire mode occurs when there is no insulating material between the bridgewires and the sensitivity of this firing mode (arcing between bridgewires) depends upon the spacing of the bridgewires and the characteristics of the explosive mix. There appear to be several alternative modes by

which the EED in an air bag inflator module could fail when subjected to electo-magnetic energy. The susceptability of the EED depends upon the length of unshielded wire, separation distance of cable from car frame, pin configuration of EED, quality of shielding provided, any attenuation by switches, and the impedance of the EED. The automobile industry is well aware of the implications surrounding these various deployment modes and has initiated several filter design features to insulate and protect the EED from inadvertent initiation caused by electromagnetic radiation.

The introduction of various RF shielding provisions into the design of the air bag module represents an attempt by the automobile industry to minimize any inadvertent deployments during normal use conditions. It would appear that this goal of minimizing inadvertent deployments associated with electromagnetic radiation is somewhat at odds with the application of radiation sources to assist in the deployment of obsolete or retired air bag inflators.

4.4.2.2 Other Concerns

There are several other principal concerns related to the use of radiation sources to deploy obsolete or retired air bag inflators. A major consideration relates to the widespread distribution of a source of electromagnetic radiation (there are over 15,000 junkyards currently operating) into the hands of the uninitiated and untrained[8]. Also, recent concern regarding the impact of low level radiation sources upon human health strongly legislates against the use of such a device at junkyard operations. Further questions relate to insuring the security of the radiation source, maintaining proper calibration, training personnel, and monitoring operating personnel to insure that chronic health hazards do not occur[9]. It must also be recognized that the radiation source would be an attractive target for thieves and vandals who could utilize the equipment to deploy air bags in vehicles during their normal operating condition. It is easy to synthesize a scenario whereby a radiation device is stolen from a junkyard and then directed toward deploying the air bags in vehicles which are traveling

along a crowded highway. It is possible to institute several precautions to insure the integrity of the radiation source but these are easily circumvented by the perservering vandal or thief. In conclusion, given the extensive attention which has been directed by the automobile industry at insulating the EED from stray radiation and recognizing the inherent problems with policing the proper handling of radiation sources at dismantlers, it appears that the use of radiation sources to deploy obsolete inflators should undergo further study and evaluation.

4.4.2.3 Alternative Radiation Sources for Inflator Deployment

There are four categories of electromagnetic radiation which could be applied to deploy retired air bag inflator modules. These include in decreasing order of wavelength, radiowaves, microwaves, lasers, and ultraviolet. Each of these individual sources would require that the inflator squib be specially modified and that new electronics and receivers be incorporated into the inflator design. Also, the use of microwaves, lasers, or ultraviolet also requires that the steel inflator housing be modified to include the provisions for an optical window which will transmit the light source to the receiver. The present steel housing presents a very effective optical shield and must be redesigned if deployment based upon optical principals is to be effective.

It is also advisable to incorporate a device which would serve to direct the optical beam and increase the probability that the radiation source will be focused upon the optical window. A frangible disc could be mounted into the firewall or the glove compartment of the car. This disc would serve as an access port into which would be inserted the deployment device. The correct insertion of the radiation gun into the disc would automatically focus the beam upon the optical window. Also, depending upon the nature of the radiation source, special receivers may be necessary. A wave guide would also be required for the focusing and directing of the laser beam.

There is the possibility that stray sources of UV or microwaves could be encountered during normal use of the motor vehicle. However, the incorporation of the frangible disc an an integral part of the inflator module should prevent inadvertent deployments.

Each of these radiation sources provides a mechanism which could be employed to deploy retired air bags. As with other deployment sources, there are unanswered questions regarding feasibility, cost, security provisions, maintenance, safety and effectiveness which must be answered before one source can be identified as a superior device for use in inflator disposal programs.

4.4.3 Mechanical Impact

The application of mechanical energy to the detector of an air bag equipped vehicle can cause the deployment of the inflator module. The success of this deployment tactic requires the presence of an electrical (d.c.) source to fire the circuit as well as the obvious requirements that both the detector and wiring system be maintained in an operating condition. One approach to initiating the deployment would involve raising the vehicle via a crane to approximately 20-25 feet off the ground and releasing the hulk with the engine compartment impacting upon the ground[10]. The forces resulting from the impact would be of sufficient severity to cause the detectors to actuate and fire the air bag. Obviously, the air bag system must be operational for the deployment to become complete. It may be possible in certain situations (series wiring configuration for the inertial and g-force detectors) that only one dectector activates with the result that the air bag does not deploy. However, the possibility for this occurring appears to be rather remote. A more probable mode for failure to deploy would be caused because either the detectors were non-operational, the wiring was defective, or the electrical source was absent from the car.

There are some concerns regarding whether all dismantlers are equipped with a crane of sufficient size to raise the passenger car off the ground and release it in order to cause deployment of the air

bag inflator. Most available cranes would be too small to raise the vehicle the required distance. Also, the front grill, hood, and bumpers are the most valuable component of the recycled vehicle and dismantlers would be hesitant to damage this section of the car. A more practical approach for employing mechanical initiation modes would relate to its incorporation at automobile shredding facilities where large scale cranes are used to charge automobile hulks to the conveyor feeding the hammermill shredder[11]. However, the implementation of this approach could cause disruptions in the rate at which vehicles are fed to the shredder. Disruptions relate to the requirements for inspecting the junked vehicles to verify that the air bag is present and non-deployed, to insure the presence of a (dc) power source (the battery probably was removed by the dismantler prior to transfer to shredding) prior to lifting and dropping the vehicle and acknowledging the deployment of the air bag module. The incorporation of this series of operations would probably necessitate the utilization of one additional crane at the shredder facility. This would enable one crane to be dedicated solely to charging the shredder while the second was involved in the preliminary operation addressing the requirements to deploy the air bag inflator.

The extreme variability in the physical condition of retired motor vehicles (wiring integrity, detector condition, presence of a battery) plus the lack of suitable equipment (large cranes) at scrapyards indicates that the mechanical mode of air bag deployment, if successful at all, may be restricted to use at automobile shredding facilities. Also, the costs associated with the purchase of a large crane can be excessive and in most instances would be beyond those normally considered as acceptable for capital investments at small or moderate-sized scrapyards. There does not appear to be any potential health or safety hazards associated with the provisions for mechanical deployment. However, the situation may require further evaluation to insure that all concerns have been properly addressed.

4.4.4 Thermal Radiation

The deployment of inflator modules could be initiated through the direct of indirect application of thermal energy to the inflator casing. The direct application of heat could be achieved through the use of an oxy-acetylene torch which is a common piece of equipment found in nearly every junkyard or scrapyard. Another approach could involve the incineration of the entire vehicle but the procedure is costly and may not be compatable with EPA regulations for airborne releases of pollutants. Another advantage to this mode of deployment is that the initiator operates directly upon the inflator module and eliminates the need for any interaction with either the air bag wiring system or the detection devices. Also, both approaches are rather straightforward but do require the presence of special equipment.

The direct application of heat to the inflator module requires that personnel work in close physical proximity to the air bag. This could result in the occurrence of injuries associated with the deployment of the air bag. Potential injuries are particularly apparent for those situations where the passenger inflator was being heated with a torch. The completion of this operation requires that the employee lie on his back to access the unit through the front passenger compartment. This awkward position exposes the employees face and upper torso to the impact of the deployed bag. Also, the unexpected inflation of the bag can cause the sudden displacement of scrap metal or glass fragments contained within the vehicle and these could injure the employee. Also, the cutting torch could be struck by the inflating bag resulting in both a potential fire hazard as well as the occurrence of possible burns to the torch operator.

Tests have indicated that the direct application of the cutting flame to driver or passenger inflator units can cause deployment to occur in approximately 5 minutes. Furthermore, if an oxygen augmented cutting flame is applied to the inflator, the case can be cut after approximately 8 seconds when preceded by a 10 second preheat phase. Therefore, the deployment can be thermally actuated in a very short

period of time if the module is thermally cut. However, if the mode of deployment is solely through heating of the module, the period required to initiate deployment can extend upwards of 5 minutes.

It appears, based upon the available information, that the thermal deployment of inflator modules which have not been previously removed from their mounting bracket within the motor vehicle can pose risks of acute injury to scrapyard workers engaged in such deployment operations. The nature of these acute risks include the possibility for burns as well as lacerations and contusions caused by workers being struck by any glass or metal fragments propelled by the force of the deploying air bag. The application of direct thermal energy to the inflator module necessitates that workers operate in close proximity to the inflator and this requirement serves to exacerbate any potential risk associated with acute injury. Therefore, it appears that the use of thermal mechanisms to deploy inflator modules, though being effective and relatively inexpensive, expose employees to significant risks of injury which are of sufficient severity to require that the use of thermal deployment be carefully evaluated prior to its introduction.

4.4.5 Electronic Lock

The keyhole-less electronic lock is a passive device which was developed for a unique class of applications where a high degree of security is desired and vandal-proofness is assured. Since there is no visual presence of a lock, the lock cannot be vandalized by the insertion of foreign matter into the keyhole, nor does it present the usual focal point for compromising the lock mechanism.

The lock is uniquely designed for applications such as vending machines, cash drawers, cabinet of office doors, file cabinets, etc. It contains an electromagnetic coil, code identification circuitry, and a bolt actuation mechanism. The entire lock electronics and mechanism are normally passive and there is no battery contained therein nor any other source of electric power. As presently designed, one of 32,768 different combinations is available for each lock.

The key is the size of a hand calculator. It contains the prime source of electric power, a rechargeable battery, electronics, coding circuitry and an electromagnetic transmitting coil.

The lock is actuated by first properly locating the key with respect to the lock such that appropriate transformer action develops between the key and lock. This action energizes the electronics and the code identifications circuitry in the lock. The key transmits electromagnetic energy to the lock to activate the electronics and simultaneously also transmits the key code. As soon as the lock identifies the proper code which mates with its internal code, then the lock bolt is actuated to the open position.

Some of the unique features of the keyhole-less lock system are that the key can communicate and actuate a lock even though the lock is in a completely sealed enclosure which can be as thick as 1/4-inch of stainless steel. Furthermore, possession of the key does not guarantee access unless one has prior knowledge as to where it should be applied since there is no keyhole.

The keyhole-less electronic lock was developed for commercial application and is presently in pilot production. Four patents have been issued on this technology and others are pending.

Large scale production of electronics and the pick-up coil would involve an expenditure of approximately $4.00 per vehicle. The deployment key can be produced for $500--$1,000 per location.

It is premature at this time to address questions regarding the procedures as necessary for scrambling the coded signal or the possible frequency which inadvertent deployments might occur. Such questions can only be addressed in a more detailed hardware oriented study.

4.4.6 Ultrasonic Deployment

An ultrasonic transmitter could be employed to provide the stimuli to activate deployment of the squib. Ultrasound does not provide energy, and must be coupled with the appropriate receiver and electronic circuitry to complete the ultrasonic link. The actual triggering of the squib would be achieved through the electronics of the system.

There appear to be several potential problems associated with the application of ultrasound. One relates to the possibility for interference caused by devices such as remote control television tuners and home burgler alarms. Also, the massive steel housing encompassing the inflator module would not be penetrated by the ultrasound unless there was a very substantial signal being generated. The requirements for a substantial signal plus the acknowledgment that a variety of interferences exist, indicates that ultrasonic actuation may not provide an attractive approach for deploying air bag inflator modules.

4.4.7 Piezoelectric Deployment

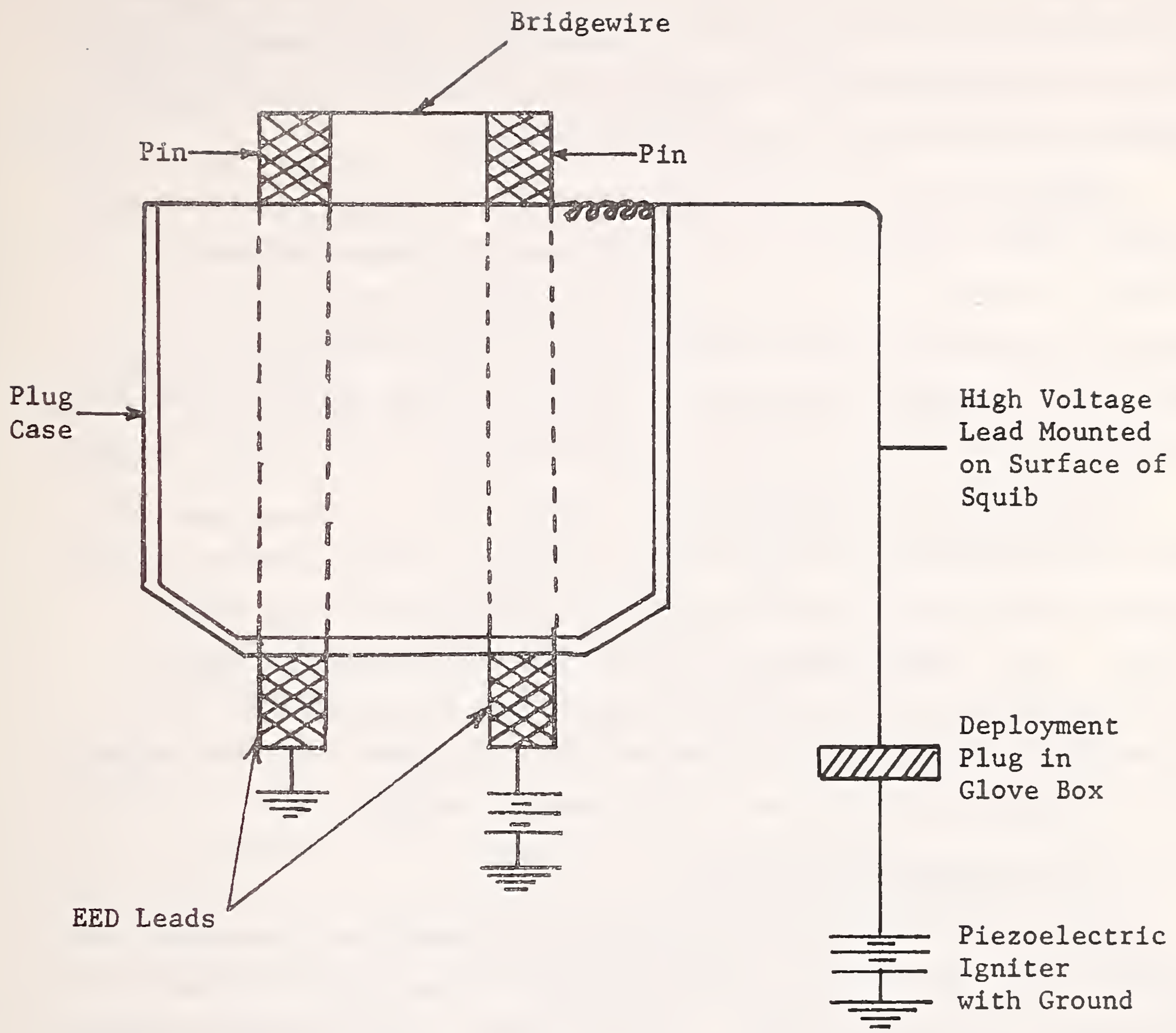
The application of piezoelectric* igniters provides a realistic solution to the problem of the safe handling and disposal of retired air bag inflator modules. The piezoelectric igniter does not provide sufficient power to heat the squib ignition coil and cannot serve as a batteryless device to deploy the squib [12]. However, communications with the Vernitron Piezoelectric Division indicates that squibs can be ignited by a piezoelectric igniter if the spark is allowed to pass over the surface as opposed to through the surface of the powder[13].

The transmission of the spark through the surface can be achieved by a simple modification to the squib design. This modification, shown in Figure 4-2 will enable the squib to be fired by either a low voltage-hi-current source (12 volt dc battery) or by a high voltage-low current source such as the piezoelectric igniter. The design modification is straightforward and involves laying a third wire on the surface of the squib powder before the unit is epoxy dipped.

The deployment circuitry involves connecting the third wire to a point of convenient access either in the passenger compartment or on the vehicle firewall. This wire then provides the lead to which the high voltage source is attached. The piezoelectric device is grounded by a clip connector and then attached to the third wire lead. The igniter is then fired and the charge causes the squib to deploy.

There is a margin of safety incorporated into this device in that an extremely high voltage (15,000 volts) low amperage charge is necessary for activation. However, it is important to note that piezoelectric igniters may be readily available through several sources. Standard igniters have energy outputs of 4.5 mJ, minimum operating life of 100,000 cycles and offer moisture resistence.

*Piezoelectric - Crystalline like materials which upon mechanical reorientation of crystalline structure generate large voltages and low current.



Source: Arthur D. Little, Inc. estimates based upon available information.

Figure 4-2

SQUIB MODIFICATIONS FOR PIEZOELECTRIC DEPLOYMENT

Piezoelectric devices can be purchased for approximately $5.00 each with volumes of 10,000 being priced at $2.00 each. Therefore, costs for the device do not appear to be a deterrent. The incremental costs for the squib device plus the added wiring required to attach a plug connector should be less than $2.00 per vehicle.

Some questions arise regarding the relative merits of the piezoelectric device versus the simple deployment by dismantlers with a 12 volt dc battery. The piezoelectric deployment requires that the squib be modified and that a lead wire be located at either the firewall or the passenger compartment. Neither of these modifications are required if the device is deployed through the use of a 12 volt battery.

In conclusion, the piezoelectric device does provide a possible source for deploying air bag inflator modules. The application of the igniter requires squib modifications and alterations in the system wiring. These design changes, plus the ease with which the piezoelectric igniters can be obtained suggest that the application of piezoelectric stimuli does not provide any deployment benefits beyond those associated with the use of a 12 volt dc battery.

4.4.8 Collapsible Partition

The concept of the collapsible partition provides a basis for automatic deployment of the inflator module during operations such as shredding, shearing, or baling. The unit could also be deployed via a direct blow from a hammer or other heavy object. The collapsible partition consists of a deformable housing which encloses the inflator module, the appropriate sensing device to detect a given level of structural deformation, and the associated electronics which would transmit a signal to cause activation of the inflator module.

There are several questions regarding the viability of this approach and these primarily relate to problems of calibrating the partition such that it is not susceptible to inadvertent deployment during installation, repair or servicing. Also, the partition should be isolated such that it is not easily accessible to vandals or other individuals with malicious intentions.

There are several stimuli which could be used to deploy the inflator following actuation of the partition. A physical stimuli such as that associated with a stab igniter could provide the mechanical deployment. Alternatively, a piezoelectric device could be mechanically coupled to the partition system and this would generate a high voltage source to initiate the inflator module.

It does not appear as though the collapsible partition provides an acceptable solution to the problem of air bag deployment. Implementation of the design builds a level of redundancy into the air bag which is neither necessary nor desirable. Also, the complicated nature of the design requirements is not compatible with the goals of maximizing systems reliability during normal use.

4.4.9 Addition of Self-Igniting Match to Inflator

There are sources of information which indicate that air bag inflators can be processed through automobile shredding and baling equipment with few adverse effects upon the processing equipment or operating personnel [14]. However, the few available data indicate that some inflators may fragment but not deploy during shredding. Therefore, sodium azide may be found as an undesirable contaminant in both process waters and fluff residues as well as within the various metallic fractions resulting from shredding. Therefore, it is desirable to insure that the individual inflators deploy during vehicle processing to insure minimal residual ozide contamination.

There are other considerations which enhance the attractiveness for developing procedures to deploy air bags at shredding or other processing locations. Firstly, there are far fewer facilities to monitor; secondly, there are minimal hardware development requirements; thirdly, there will be little, if any, additional costs associated with the program and far fewer personnel will be involved in the deployment program.

The addition of a self-igniting match to the pyrotechnic generant provides one approach which could serve to initiate ignition of the generant during shredding, baling, or shearing of retired

motor vehicles containing non-deployed air bag inflator modules[15]. The match would be calibrated to ignite at the energy level associated with deformation of the inflator. Alternatively, a pyrophoric (self oxidizing) organometallic substance such as triethyl or trimethyl aluminum or aluminum borohydride could be inserted into the inflator where it would ignite upon exposure to air.

There is little information regarding the impact of the self-igniting match upon the quality of the effluent gas generated during normal deployment of the air bag. However, the current technology for self-igniting matches should be capable of producing a match whose incorporation into the pyrotechnic would not markedly alter the composition of the generant gas.

The simple addition of the match to the pyrotechnic does not require any hardware modifications to the inflator. The minimal amount of modification to the inflator should provide a margin of safety with respect to inadvertent or accidental deployments. The squib will not be modified nor will any of the other components within the inflator. This design change is relatively modest compared with previously suggested options. The primary concerns regarding this design change relate to whether the self-igniting match will have any impacts upon the quality of the generant gas during normal deployment modes.

It has been demonstrated through previous research that a significant number of air bag inflator modules will deploy during shredding operations. These tests were conducted with inflators which had not been modified to expedite deployment and there is every reason to assume that the application of the self-igniting match would serve to increase the present observed rates of inflator module deployment. Therefore, it appears that the use of the self-igniting match could provide a convenient and reliable approach for deploying the air bag.

There are several unanswered questions regarding whether it is advisable to limit deployment until the retired vehicle enters the scrap recycling process. The presence of the live inflator in vehicles stored at dismantler/recycler facilities could result in

injury if the module is inadvertently deployed either by employees or the amateur mechanic during removal of parts from the stored hulk. Dismantlers/recyclers will often hold a car for 12-18 months during which time there are numerous opportunities for the system to be deployed. These questions of liability must be balance against the options of undertaking more radical modification of the inflator, developing deployment hardware for use by recyclers, and supervising the deployment operations.

4.4.10 Hardware Evaluations

The various options which are available for hardware modification were evaluated according to selected parameters to assess their feasibility for use in deploying retired air bag inflator modules. Several parameters were considered in undertaking the evaluation. Included were the magnitude of the required hardware design change, cost per vehicle for the design change, impact of the design modification upon inadvertent deployment of the air bag module during normal use, ease of utilization of the deployment device, impact of the design change upon accidental deployment of the air bag during servicing and repair, costs for the device, time frame for program implementation and other considerations related to employee training, health hazards and special provision for equipment storage and security.

- Required Hardware Design Changes - What are the nature of the design modifications required to adopt the inflator module to ease deployment.
- Cost per Vehicle - What are the anticipated costs per vehicle for inflator modification.
- Probability for Inadvertent Deployment - What impact does hardware modification have upon the inadvertent deployment of the air bag during normal use conditions.
- Ease of Utilization - How convenient is it to employ the suggested deployment device.
- Potential for Accidental Deployment - What is the impact of the hardware modification upon the probability for accidental deployment of the air bag during servicing and repair.

- Cost for Deployment Hardware - What are the anticipated hardware costs for the selected deployment device.
- Time Frame for Implementation - How soon can the deployment system be implemented.
- Other Considerations - What special housing or other devices are required to implement the program. Is training of workers required. Do regulations require input from other agencies.

4.4.11 Preliminary Ranking of Options

The result of this preliminary analysis of alternative hardware configurations (Table 4-1) suggests that the available options could be ranked as follows, in order of decreasing attractiveness:

- dc electric
- piezoelectric
- electronic lock
- self-igniting match
- induction coil
- UV
- radio frequency
- laser
- microwave
- ultrasonic
- collapsible partition

Based on electromagnetic radiation

It is apparent that the dc electric, piezoelectric, electronic lock, and induction coil are superior and separable in terms of their attractiveness as deployment devices. In other instances, it is difficult to differentiate between specific groups of options and select that which is clearly superior. The deployment options based upon the use of electromagnetic radiation sources are an example in point. The costs per vehicle for the hardware appear comparable, as are issues related to inadvertent and accidental deployment, ease of utilization, and time frame for implementation. Therefore, it is difficult to identify the preferable choice from the available options.

TABLE 4-1

CONSIDERATIONS FOR HARDWARE MODIFICATIONS

Parameters Considered	12 Volt dc at Auto Dismantler	Radio Frequency Tuned Squib	Ultrasonics	Piezoelectric
Required Hardware Design Changes	Add plug connector to firewall or passenger compartment	Modify the squib, including filters and electronics to ease deployment for a specified signal.	Require modifying the module to include new electronics receiver to couple ultrasonic link. Squib may need modification.	Requires modifying squib design by adding a third surface lead and connecting this lead to the firewall or passenger compartment.
Cost/Vehicle	$2.00	$10.00-$15.00	$10.00/$15.00	$2.00-$5.00
Probability for Inadvertent Deployment	Low, system will be essentially unchanged. Current design emphasizes protection from inadvertent deployment	This will increase because of reliance upon radio signal to cause deployment. Problems with screening or filtering out stray signals. Uncertainty regarding how the vehicle will respond as an antenna.	Subject to interference by burgler alarms, remote control T.V. tuners, etc.	Uncertain as to how squib modification will effect the receiver characteristics of squib.
Ease of Utilization	Requires that employee attach 12 volt source to connector and fire remote switch.	Automatic remote deployment, no employee contact with inflator.	Automatic remote deployment, no employee contact with inflator.	Requires employee to attach piezoelectric igniter to squib lead, ground circuit, and deploy remotely.
Potential for Accidental Deployment	High, anyone with the dc source could access the plug and deploy air bag.	Diagnostic equipment at service stations could cause interference.	Not likely to occur during servicing, repair or due to vandalism	Need high voltage source, plus direct contact with vehicle. Not possible to generate high voltages through stray radiation.
Cost for Deployment Hardware / Location	Less than $50.00 for battery, leads, switch	$500-$1,000 for commercial radio transceiver.	$1,000 for transmitter.	$4.00-$5.00 for igniter plus $5.00-$10.00 for leads and switch
Time Frame for Implementation	Immediate	1-2 Years	2-3 Years	1-2 Years
Other Considerations	No special housing or security required for deployment device. No apparent hazards to worker health or safety.	Special housing and security required for deployment device. FCC approval may be necessary. Employee training required.	Special hearing protection may be required. Shielding also necessary. Employee training and security program required.	No requirements for personal protective equipment. Employee training required.

TABLE 4-1 CONSIDERATIONS FOR HARDWARE MODIFICATIONS (Contd)

Parameters Considered	Collapsible Partition	U.V.	Microwaves	Laser
Required Hardware Design Changes	Redesign of inflator to include new housing, sensors and electronics	Redesign of squib and module to include optical window. Otherwise, beam will not penetrate inflator. Receiver must also be added to system electronics. Provide frangible disc to direct beam.	Requires redesign of module to include optical window. Squib must also be redesigned. Provide frangible disc to access the optical window with radiation source.	Modify the inflator to include optical window. Redesign squib, add frangible disc to provide access for laser beam. Optical wave guide require
Cost/Vehicle	$20.00-$30.00	$15.00-$20.00	$15.00-$20.00	$15.00-$20.00
Probability for Inadvertent Deployment	Increased, depending upon sensitivity of the partition.	Module design could compromise the antenna characteristics of the inflator. There are also several sources of U.V. in the environment.	Microwave energy is transmitted by television, FM and radar transmitters. Therefore, there could be high probability for inadvertent deployment.	Low inadvertent deployment Will depend upon final squib configuration. Also the circuit may behave differently with respect t its antenna properties.
Ease of Utilization	Automatic activation upon deformation of the partition. Dismantler would strike the unit with a hammer, or other device.	Requires focusing of U.V. source on optical window. Remote deployment is possible.	Requires focusing of beam on inflator module. Optical window provides access for remote deployment	Laser gun is normally inserted through frangible disc and activated for remote deployment.
Potential for Accidental Deployment	Service personnel, owners and others could cause deployment by handling or striking the housing.	Welding operations and other U.V. sources could be problematic. Sunlight and artificial light source may cause problems. Frangible disc limits access.	Frangible disc restricts access for optical window.	Sources of laser radiation are not generally expected near the vehicle environment. Frangible disc restricts access.
Cost for Deployment Hardware/Location	Occurs automatically during shredding, shearing or baling. Dismantlers can deploy easily.	$1,000-$2,000 for transformer, regulator and high pressure mercury vapor light source. 110 volt service required.	Depends upon whether pulsed or continuous wave modes are used. Higher power associated with pulse waves. $150.00-$1,000.00	$2,500-$3,000 depending upon power requirements and whether pulsed or continuous. 220 volt service required.
Time Frame for Implementation	1-2 Years	2-3 Years	2-3 Years	3-5 Years
Other Considerations	This builds a level of redundancy into design which is not necessary. Also, could cause problems during assembly. Requires integrity of wiring system plus power source or other device to stimulate the initiator.	There appear to be many sources of stray U.V. which could cause deployment of air bag. Provisions must be made for eye and skin protection. Training programs also required.	Appropriate shielding and housing of device is required. Employer training plus use of protective equipment is necessary. Rigid guidelines exist for allowable employee exposures. General concern regarding health hazards of low level radiation is a problem.	Lasers require employee training plus use of eye protection equipment. Provision should also be made to insure security of the laser. Health standa[illegible] may preclude use. Warnin[illegible] signs are necessary.

TABLE 4-1 CONSIDERATIONS FOR HARDWARE MODIFICATIONS (Contd)

Parameters Considered	Electronic Lock	Inductive Coil	Self-Igniting Match Added to Pyrotechnic
Required Hardware Design Changes	Modify inflator to include new electronic receiver, pick-up coil, frangible disc to insert electronic key.	Modify inflator to incorporate an induction coil and alnico magnet in a separate circuit. Shield required.	Add either a self-igniting match or a pyrophoric organmetallic to the generant chemicals which would ignite during shredding, shearing or baling.
Cost/Vehicle	\$5,00-\$10.00	\$5.00-\$10.00	\$.25-\$1.50
Probability for Inadvertent Deployment	Low because of coded signal. However, it is uncertain as to how the modified circuitry will behave relative to an antenna.	Shield should protect the circuit against inadvertent deployments.	Low unless the match interferes with the antenna characteristics of the inflator or modifies the chemical properties of the generant.
Ease of Utilization	Requires physical contact between transmitter and receiver built into module.	Requires physical contact between coils to generate the field necessary to fire the system.	Requires a physical force to deform the inflator and cause the match to ignite.
Potential for Accidental Deployment	This is related to the specifics for the key device and its power and frequency characteristics.	May be possible to energize coil through use of diagnostic repair equipment.	There should be no impact upon frequency for accidental deployments.
Cost for Deployment Hardware/Location	\$150.00-\$1,000 for coded source.	\$100.00-\$500.00	No cost for hardware deployment. Deploys upon shredding, shearing or baling.
Time Frame for Implementation	1-2 Years	1-2 Years	Immediate - 1 Year
Other Considerations	Electronic lock requires that the key contact the inflator module. This could result in employee injury. Employee training is required.	Employee training required. May require that employee work in close proximity to inflator.	Deployment during scrap operations raises questions regarding liability if module deploys at dismantler. Also, some concerns whether match would modify composition of gases released during normal deployment.

Source: Arthur D. Little, Inc. estimates based upon available information.

The procedure applied to evaluate the alternative hardware modifications did not involve the use of weighting factors to differentiate between individual parameters. In some situations it may be necessary and desirable to apply variable weighting factors for individual parameters. The use of weighting factors should be considered when there are clear indications that one or more of the scoring parameters is definitely more important relative to the achievement of a specific goal. For example, it appears that costs for modifying the inflator module are small ($5.00 - $15.00), relative to the estimated overall costs for the air bag restraint system and therefore costs might be weighted by a factor of 1. However, system reliability relative to inadvertent deployment is extremely important and,given the extensive efforts that have been directed toward maximizing reliability, this parameter might be weighted at 10 or higher, depending upon an overall assessment for liability issues. Finally, issues such as time frame for implementation and ease of operation might be weighted at 2 or 3, relative to other considerations.

The use of individual weighting factors is often effective for providing a mechanism to "spread out" or better differentiate between alternative options. For example, if upon initial examination there exists a clustering or grouping of differing options, then these groups may be re-evaluated with the application of weighted parameters. This follow-up or second-level analysis can provide valuable insight regarding any subtle differences between individual alternatives. This second level of evaluation was not undertaken during this program and would require a level of analysis beyond the scope of this current study. However, there are several procedures which might be employed to develop individual weighting factors. The application of the Delphi approach has historically been one method for assessing the relative impact of individual variables toward the overall achievement of a specific goal. Several iterations of an independent group evaluation are often required before convergence can be reached regarding the value for individual weighting factors. Convergence is influenced in many instances by the provision of feedback information which enables each judge to assess his weighting considerations relative to those of his peers.

4.5 Control of Generant Chemicals at Shredding Facilities

There is some concern regarding the procedures which should be employed to properly dispose of pyrotechnic generant chemicals which are released from inflators during the scrap recycling process. Shredding, shearing, and baling of vehicle hulks can result in the release of generant chemicals which may become dissolved in process wash water or released into the areas immediately adjacent to the processing location. There are several possible approaches which could be employed to minimize these releases of generant chemicals. The most obvious solution would be the provision to insure that inflators are deployed at the dismantler facilities and do not enter the shredding or shearing process. There is no guarantee that all modules entering the reclamation facility will be deployed and countermeasures such as on-site neutralization of azide or encapsulation of the generant pellets to limit their toxicity are required as part of a program for hazard reduction.

- Encapsulation - it is possible to encapsulate pyrotechnic materials with polystyrene, nitrocellulose lacquers or related materials[16]. The Wurster Process involving air stream drying provides a protective coating which can serve a variety of functions. Included among these are prevention of moisture absorption, reduction in abrasion between adjacent pyrotechnic surfaces, and safer handling during manufacture. These potential advantages must be weighed against the possibility that the encapsulating material will alter the performance of the pyrotechnic material and influence either the deployment reliability or alter the characteristics of the effluent gases. Thiokol has experimented with the encapsulation of sodium azide and the application of nitrocellulose lacquers altered the gas generating characteristics of the pyrotechnic resulting in excessive levels of CO.[16]

It appears that the encapsulation of azide to reduce its potentially toxic effects requires additional research. The stringent performance specifications for the gaseous effluents mandates that little, if any, carbonaceous material (which generates CO and CO_2 upon

combustion) can be used in the coating of the combustible generant.

- Neutralization - It is possible to neutralize sodium azide with an acidic solution of sodium nitrite. The reaction for this neutralization indicates approximately .80 pounds of sodium nitrite and .23 pounds of sulfuric acid are required to neutralize the 350 grams of azide typically found in both the driver and inflator module. It is important to recognize that these neutralization reactions do not acknowledge the numerous contaminants which are present in the wash water baths at metal recycling operations. The impact of these contaminants upon the reaction kinetics cannot be evaluated based upon existing information.

The costs for the neutralization process, assuming that it is compatable with current scrap processing, is approximately $.75 per processed vehicle (if 350 grams of azide/vehicle is available for reaction). Conversations with personnel at Thiokol Corp. indicate that the estimated costs for neutralization chemicals appear reasonable[17]. However, it is important to recognize that many questions remain regarding the procedures necessary to store and feed the chemical and the precautions which are necessary to handle any side reactions which might occur due to contaminants in the wash water.

The available information regarding the procedures available for both encapsulation of sodium azide pellets and neutralization of azide pellets suggest that each process requires extensive study. It appears that a more feasible solution to potential human health and environmental hazards caused by azide at metal reclamation facilities would involve procedures to insure that retired inflator modules are deployed prior to arrival at the recycling facility. This would insure that any potential health or environmental pollution problems are minimized. The gaseous effluents generated during deployment of the inflator are clearly much less hazardous than the sodium azide which serves to generate the gas.

4.6 Salvage, Recycling and Reuse of Inflator Modules

It has been suggested by various individuals that the retired inflator module may be successfully recycled and reinstalled in

passenger vehicles after a period of refurbishing, calibration and testing[18]. The individual pyrotechnic inflators are considered to be relatively simplistic from a design perspective and if the pyrotechnic gas generant and squib do not undergo degredation or aging during long term usage then it may be possible to recycle the individual inflators as well as the air cushion. It is apparent that at this point in time issues of reliability would preclude the reuse of retired inflator modules. However, as the technology advances it may be possible to adapt the units such that they can be recycled.

The possibility of recycling raises many questions regarding the issue of reliability and liability associated with malfunction of a recycled air bag inflator. More specifically, who assumes the liability or responsibility for the performance of the recycled bag. Does this rest with the original manufacturers (e.g., Talley, Thiokol, Hammill) or with the car manufacturer in whose vehicle it was originally installed, or with the mechanic or service representative who performed the re-installation of the recycled unit. Questions such as these have to date not been addressed in sufficient detail to justify consideration for the possibility of recycling air bag inflator modules.

It is possible to draw an analogy between the recycling of air bags (not for direct reuse, but for other monetary or resale purposes) and the salvaging of spent catalytic converters by scrap dealers. It has been forecast that in excess of $400 million dollars in precious metals are presently found in catalytic converters. Also, over 40% of the U. S. consumption of platinum metals is directly related to the auto industry. Retired and spent converters can provide valuable sources of precious metals and this type of philosophical recycling argument could be developed for passive restraint equipment where the inflator, certain of the sensors and perhaps the diagnostics could be retrieved from the vehicle and recycled.

Individual dismantlers have expressed some interest in the possibility for the development of a market for recycled inflators. It appears that an individual unit could be removed from a car in appproximately 20-30 minutes depending upon the degree of care and

individual safety precautions which are necessary. The time requirement, plus the need for any special equipment, handling or storage procedures requires that a price of at least $30.00 be received for the individual inflator[19]. This value would enable the recycler to maintain a satisfactory level of profit to encourage his participation in the recycling program and thereby insuring a supply source for retired inflator modules. Special procedures which may be required of the dismantler include the necessity to store inflators in a secure location where they would not be subjected to vandalism or other abuse. Also, it is necessary to develop a procedure or procedures for the collection, refurbishing testing, and repackaging of individual units prior to resale. The subtle design variations between individual manufacturer modules may preclude establishing a uniform methodology for recycling of inflators, Therefore, NHTSA, individual insurance carriers, or manufacturers may be required to adopt minimum performance specifications for the recycled inflators.

The development of a procedure for the recycling of air bag inflators could be easily incorporated into a motor vehicle safety inspection program which would involve the reuse of equipment which can directly effect the lives of the American public. Therefore, it is desirable to restrict the number of individual firms engaged in the recycling effort to better monitor their operations. Individual service stations are not equipped to properly handle inflators. Also, their participation in such a program could jeopardize its effectiveness because of the possible influence of individuals who would be prepared to compromise or circumvent the normal channels for recycling and distribution. Any successful program for recycling air bags must involve close supervision over a limited number of operating facilities. This widespread involvement of poorly equipped operators will only lead to numerous monitoring and surveillance problems.

4.7 Results

This analysis was undertaken to assess whether inflator modules could be modified to assist in the safe handling and disposal of retired air bags. Various types of hardware modifications were identified

as potential candidates for use in the deployment program. A series of evaluation criteria were selected and each alternative deployment methodology was evaluated according to the individual scoring criteria. The information was presented in a matrix format and each candidate system can be evaluated relative to competitive proposals.

The results of the analysis indicate that most of the hardware modifications require that some alterations be made to the inflator. The extent of these are variable and range from modification in squib design to installation of an optical window and electronic receiver. Each deployment proposal requires rather extensive hardware modification with the exception of the approach involving the use of a 12-volt dc battery applied through a remote switch. It is not possible during this program to specify the exact nature of specific hardware modifications. It is possible, however, to indicate that most options will require major changes in the inflator module design. The degree of design modifications is also closely correlated with the anticipated cost increases per vehicle.

The sophistication of the various deployment devices is extremely variable and spans technologies which include the application of a simple 12-volt dc source as well as those employing a powerful pulsed laser. A majority of the deployment devices could be considered as portable and requiring modest capital expenditures (<$1,000.00). The time frame for implementation of the deployment program depends heavily upon the availability of appropriate hardware and generally varies from 1-3 years following initiation of the research effort. Only the 12-volt dc deployment mode could be initiated in less than 1 year. All of the potential devices will contribute to a higher rate of inadvertent deployments. However, the rate of accidental deployments will be variable depending upon the nature of the stimulus required to fire the squib. For example, more inadvertent deployments would be anticipated with the use of radio frequency stimuli than with a deployment protocol based upon ultrasonic or laser principles.

All modes of deployment require that the employee be informed of the hazards surrounding his job and that appropriate training be

provided to insure that both good work practices and personal protective equipment are employed to protect worker health and safety.

4.8 Recommendations

An examination of the information presented in Table 4-1 indicates that there is only one method of deployment which is immediately available for implementation. The use of a 12-volt dc power source applied through a remote switching operation provides a safe and effective mechanism for deploying air bag inflators. There are no requirements for major hardware modifications which could compromise the reliability of the air bag. Costs to both the automotive manufacturer plus the dismantler are lower than those for any other option under consideration. Safety and health hazards are minimal and problems with inadvertent deployments are limited. If there are any shortcomings associated with this system, they relate to the ease with which the unit can be deployed by anyone with a 12-volt dc source. However, security precautions can be provided to insure that the plug connector is properly protected and that access requires the use of appropriate tools for removal of a special protective cover plate.

The other deployment options which are shown in Table 4-1 require what could be described as considerable modifications to the inflator design plus the use of deployment devices which require high levels of employee training, special housing and security precautions, or use of other precautionary procedures. The second most attractive method for disposal incorporates the system requiring squib modification and activation through the use of piezoelectric device. The squib modification is trivial, costs for the igniter are low and inadvertent deployment appears minimal. However, piezoelectric igniters produce very little energy (milli-joules) and there is some question whether this power is sufficient to cause the squib powder to actuate.

The remaining options do not appear at this time to provide realistic approaces to the safe handling and disposal of retired air bag inflator modules. However, very little, if any, basic research has been undertaken to evaluate alternative deployment procedures and

such work could be very productive in terms of identifying more reliable methods to expedite deployment[20]. The electronic locks provide one attractive approach for air bag deployment.

The available time frame for development of new air bag inflator hardware may preclude the introduction of new designs for use in 1982 air bag systems. However, it is feasible and desirable to undertake additional research on hardware modification because the lead times of 3-5 years for new technological breakthroughs will not materially impact potential disposal problems. The phased implementation program (large vehicles in 1982, intermediates in 1983, and small in 1984) provide a margin of flexibility which can enable automobile manufacturers to recognize new procedures for the safe handling and disposal of air bag inflator modules.

It is readily apparent that air bag inflators should be safely deployed early in the vehicle retirement cycle. However, the current designs for air bag systems are focused upon preventing inadvertent deployments and as such, existing designs are not totally compatible with the suggested deployment protocol. Therefore, it is necessary for the automotive industry, their vendors, and the federal government to undertake basic research to better identify and evaluate the various hardware modifications which are necessary to insure that retired air bags can be safely deployed without compromising the reliability of the inflator during normal use.

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5. MOTOR VEHICLE INSPECTION PROGRAMS

5.1 Introduction

The overall effectiveness of any passive restraint program including those activities related to the safe handling and disposal of retired air bags can be improved through the implementation of inspection and monitoring programs. The evaluation of the ready status of the passive air bag during normal use and responsibility for the safe handling and disposal of the retired inflator module could be integrated into existing mandatory programs for vehicular inspections such as those related to automobile safety and exhaust emissions.

5.2 Inspection Facilities

The concept of inspection, diagnosis, repair, replacement and disposal facilities (IDRRD) would represent designated locations where the air bag system could be periodically inspected to insure its effectiveness, maintained as necessary and safely deployed at the completion of its useful life. There are three potential organizational approaches to developing and implementing this type program. These include programs involving:

- Local Service Station/Garages
- Private Contractor Facilities
- Facilities Operated by State, Federal, or Municipal Personnel

There are several considerations which are important when evaluating the feasibility of alternative implementation programs. These include the total estimates of capital investment cost, start-up cost, annual recurring costs, and total costs. The cost of the program on a per vehicle inspected is also important as are those considerations which relate to the requirements to add state or federal personnel to operate, monitor, inforce, or otherwise participate in the air bag restraint inspection programs.

Many individual states currently employ motor vehicle safety inspection programs. A vast majority of these programs, however, do not conform with the recommendations or future requirements of the

NHTSA Vehicles in Use (VIU) Guidelines. Given the degree of non-conformance with NHTSA guidelines, it is anticipated that future safety inspection requirements and associated costs would rise. Also, recent activities including the possible development of regulatory programs related to noise control, fuel economy and crashworthiness suggest that individual states should carefully consider developing comprehensive inspection programs addressing each of these areas. The necessity to implement these additional programs requires that cost analyses be undertaken to evaluate the most cost effective methods to institute a total vehicle inspection program. This program will also include the provision for inspecting, repairing or replacing, and deploying air bag inflator systems.

5.3 Recent Programs

Recent data developed by the Commonwealth of Massachusetts for a decentralized emissions inspection and maintenance program provide information regarding the relative costs for programs provided by private contractors, state operated facilities or individual service stations which are licensed to participate in the current safety inspection programs [(1)]. These costs reflect consideration for upgrading the current safety inspection program to comply with the NHTSA VIU Guidelines, instituting an emission inspection/maintenance program and providing the requisite monitoring of the system including the provisions for validation centers to review the results of contested inspections. Two sets of analyses were conducted, one comprising 47 regional private contractor operated facilities and a second based upon the use of 4,200 decentralized private facilities which currently participate in the mandatory vehicle safety inspection program. The scope of each analysis was similar with respect to the requirements for statewide annual inspections of approximately 5.6 million vehicles for both safety and emissions evaluations; inspections performed throughout the year on a staggered basis; one free reinspection per year; minimal travel distance (<10 miles) and waiting time (<20 minutes) at each inspection location; challenge stations to assess the merit of contested inspection results.

5.4 Results for Massachusetts

The results of these survey's can be highlighted by several factors related to the costs for present safety inspection programs, the incremental burden which is associated with upgrading of these programs to comply with NHTSA VIU Guidelines, and then combining the upgraded program with an inspection maintenance procedure for emission control.

The present Massachusetts inspection program requires approximately 10 minutes to complete and includes examination of brakes, steering, and tires plus headlights, muffler, exhaust, horn, glazing and body. The upgrading of the safety inspection to comply with NHTSA VIU Guidelines require the addition of procedures for the visual inspection of:

- brake failure indicators
- brake pedal reserve
- brake hoses and assembly
- brake power unit
- power steering system
- suspension and shock absorber condition
- tread type
- wheel mounting and integrity.

Also, there are requirements for:

- mechanical inspection of wheel alignment
- a bar-type, scuff guage or other toe-in measuring device
- removal of one front wheel and one rear wheel to inspect disc and drum condition, friction materials, structural and mechanical parts.

The completion of these additional requirements is estimated to require the following incremental testing times: (2)

- Visual inspection of eight additional components at 5 minutes.
- Alignment test at 2 minutes
- Wheel pull to inspect disc and drum condition at 10 minutes.

The total incremental time requirements are 17 minutes.

The current state safety inspection program, conducted at approximately 4,200 certified service stations has a self-sustaining life sycle cost of $5.74, to this figure must be added the emission inspection and maintenance cost of $4.52 for a total of $10.26 per vehicle. If the cost of upgrading the existing safety inspection program to meet NHTSA VIU Guidelines is considered, the incremental costs, based upon an increase of 17 minutes in safety inspection time, are $9.13 per vehicle. The total inspection program costs for upgraded safety inspection plus emissions evaluation are $19.39 per vehicle. This value of $19.39 per vehicle represents a worst case situation whereby all costs, both public and private, are accounted for in the fee; no administrative economies are assumed in the public sector because of combined program administration; and all garage costs are covered by the fee. If private sector garages are permitted to repair those items which fail inspection and if public sector economics related to joint administrative for both safety and emissions are acknowledged then the fees for the combined NHTSA VIU and emissions inspection would be $14.74 per vehicle.

The comparable costs for a required program for safety and emission inspection based upon the use of 47 private contractor facilities are lower than those for the decentralized operations. The projected cost per vehicle if $10.06 compared with the $10.26 for the decentralized operations [3]. The cost comparison for the two inspection approaches indicates that there are only modest differences in the cost per vehicle. However, there are other important considerations related to the states cost burden, the potential for new construction activity, and the creation of a larger property and tax base. Each of these factors can be important concerns, but it is premature at this time to discuss their impact upon a program such as that for air bag inspections which is only in the preliminary stages of conceptualization.

These costs can be presented in terms of dollars per hour for the inspection activity and the indications are that these translate into approximately $30/hour. If it is assumed that the inspection of the

air bag can be completed automatically, then there would be only minimal costs for diagnostic hardware suggesting that the annual increment for this type program would be less than $2.00 for most vehicles. The deployment of the retired air bag would require less than 5 minutes and could be completed for less than $5.00. Therefore, if the automatic deployment of the air bag is built into the life cycle inspection costs of the vehicle, and the average life is 10 years, then the total costs for annual inspection plus deployment of the retired air bag is less than $25.00 per registered vehicle.

There are also a series of questions which can be raised regarding the relative advantages which accrue to the consumer following the implementation of an inspection program. The relative advantages and disadvantages associated with alternative types of inspection programs are shown in Tables 5-1 and 5-2.

5.5 Conclusions

The available information indicates that the private contractor operated regional inspection facility would provide an acceptable approach for both inspecting the functional readiness of the air bag restraint and providing the capability to deploy the unit following retirement of the motor vehicle. This service would be integrated into existing programs for vehicle safety inspections and other activities related to monitoring of the performance for emission control devices.

TABLE 5-1

Evaluation of Alternative Structures for Inspection Programs

Program	Structure	Advantages	Disadvantages
Private contractor operates regional centers under state supervision	Combined safety/emission inspections performed throughout the year on a staggered basis. Maximum travel distance 10 miles and waiting time less than 20 min. Cost per inspection \$8-\$10. 40-50 state employees needed for enforcement and administration.	Consumer protection because repair is separate from inspection. Fewer stations to monitor. Flexible working hours for consumer convenience.	Fewer inspection stations means longer travel distances.
Private repair garages currently licensed by state to provide expanded inspection programs. Repairs also provided by inspection stations.	Decentralized locations provide inspections staggered on a monthly basis. Challenge facilities are structured to validate contested inspection results. 60-70 state employees required for enforcement. Consumer cost \$8-10 per inspection.	Larger number of inspection facilities reduces travel and waiting time. Maintenance provided at inspection location, one-stop operation.	Permission to repair the defective equipment could lead to fraud. May be difficult to effectively monitor large number of stations.
State-owned and operated facilities	Similar to private contractor except all employees are state personnel. Requires 650 employees.	Similar to private contractor except state would provide the inspection at cost.	Similar to private contractor except for increased state payroll and longer start-up period.

Source: Arthur D. Little, Inc. estimates based upon available information.

TABLE 5-2

Consumer Advantages and Disadvantages for Alternative Inspection Programs

Program	Consumer Advantages	Consumer Disadvantages	Consumer Safeguards
Private contractor operates regional center under state supervision	• Inspection separate from repair, no conflict of interest • Independent basis for judging performance • Ease of monitoring performance • Data collection facilitated	• Adequacy of service industry to perform repairs • Public ignorance of causes for inspection test failure • Adverse reaction regarding role of profit-making organization in inspection program	• Mechanic training • Public eduction
Private repair garages currently licensed by state to provide expanded inspection program	• More locations, less travel and waiting	• Data collection difficult • Adequacy of service industry to perform repairs • Public ignorance of causes for inspection test failures • Inspection not separate from repairs, possible conflicts • Hard to insure inspection uniformity	• Mechanic training • State referee garages • Certification of facility • Consumer action programs • State licensing and surveillance • Public education program • Specified recordkeeping requirements
State-owned and operated facilities	• Inspection separate from repair, no conflict of interest • Independent basis for judging performance • Ease of monitoring performance • Data collection facilitated	• Adequacy of station to perform repairs • Public ignorance of causes of inspection test failures	• Mechanic training program • Public education program

Source: Arthur D. Little, Inc. estimates based upon available information.

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6. MONETARY BASED PROGRAMS

6.1 Introduction

The application of fines/disincentives or bounties/incentives to encourage the proper handling and disposal of retired air bag equipped motor vehicles is in many ways analogous to similar "monetarily based" programs to insure proper handling of abandoned motor vehicles. The questions of how to reduce the prevalence and incidence of abandoned motor vehicles has been widely studied and many of the issues relevant to abandoned automobiles are germane to the question regarding how best to insure the proper handling and disposal of retired air bag inflators [(1), (2)].

It could be argued that the problems of abandoned motor vehicles and risks associated with retired air bag inflators are synonomous and the development of a solution for one problem may be applicable to the other. It is apparent that a primary requirement for the safe handling and disposal of retired air bag inflators requires that the vehicle be first delivered to a designated location where the deployment operation is completed. If the initial delivery is not accomplished, the vehicle becomes abandoned, and the proper disposal of the air bag will not occur. Therefore, it is important to insue that the number of abandoned vehicles is minimized.

The decision regarding what type of economic policy to employ, the level of payment or fine and how to administer the program can only be addressed in a generalized manner. The relative feasibility of either fine or incentive programs will be enhanced for those situations where an existing administrative or organizational structure could assume responsibility for the program. In the absence of such a structure it would be difficult to legislate, implement, and operate an appropriate regulatory program for administering a fine or fee system.

6.2 Fee or Incentives

It has previously been proposed that owners of motor vehicles deposit a fee of $25-$50 into a general fund which would be returned upon retirement of the motor vehicle and receipt of a certificate

verifying proper disposal. This same concept could be applied to encouraging the delivery of air bag equipped vehicles to either designated disposal locations or to automobile dismantler/recyclers. The initial owners fee would be included within the transaction price for those vehicles which are resold prior to final retirement. Upon retirement, the final owner would obtain a receipt veryifying that the car has been properly delivered to a designated disposal location. This receipt would be forwarded to the appropriate agency which returns the fee deposited at the time of original purchase.

The philosophy surrounding the feasibility of applying a fee system rests upon the premise that the vehicle will always have a "net value" and this incentive will encourage its return into the salvage cycle as opposed to abandonment. There are some questions regarding whether the dismantler will accept all vehicles delivered to his facility. It is not possible to speculate at this time regarding future trends in scrap prices or their effect upon the demand for retired vehicles. However, current steel industry trends toward the basic oxygen furnace have served to increase the demand for recycled scrap and there are no indications that this practice will be demonstrably changed in the future. Therefore, if the fee schedule is adequate to encourage the owner to deliver the vehicle to the dismantler, the vehicle should be accepted, and the incidence of abandoned vehicles and non-deployed inflators would be reduced.

Alternatively, the fee for handling the retired hulks could be paid to the individual dismantler/recycler. This would encourage the acceptance of retired hulks and also should be easier to monitor and administer from a regulatory perspective. This approach, however, raises the issue of whether the elimination of the fee payment from the vehicle owner will be a sufficient disincentive such that a large number of retired vehicles will no longer be delivered to the dismantler/recycler. There are clear trade-offs which must be evaluated. Included are whether the value of the fee received by the dismantler is sufficient to encourage his participation in programs to retrieve

abandoned vehicles from wider geographic locations. It is important to recognize that most dismantlers are engaged in active parts salvaging and as such do not routinely handle abandoned vehicles which have marginal value in terms of salvagable parts. Therefore, the bounty must offset any marginal costs associated with handling a vehicle whose primary value is as scrap.

For a given level of program effectiveness, it appears that the level of the fee paid to the dismantler/recycler would be less than that provided to the individual vehicle owner. The exact value of this difference is not easily measured and is beyond the scope of this program.

6.3 Fines, Penalties/Disincentives

The use of fines or penalties is not appropriate as a mechanism to increase the flow of abandoned vehicles into the scrap cycle. However, this device may be used to influence the manner in which the vehicle is handled once it arrives at the dismantler location. The level of a fine which is necessary to encourage the proper handling of a retired motor vehicle must be considerably higher than the analagous fee or bounty provided to encourage the proper handling of the retired motor vehicle. The concept of fines and penalties connotes inspection and surveillance programs and the undertaking of these activities require that they be focused upon a discrete and manageable number of locations. For example, it would be extremely difficult to provide surveillance programs at all potential locations for abandonment of motor vehicles. Any individual intent upon abandoning the vehicle would, with few exceptions, not be deterred from his intended actions by the punative implications of a fine. Also, a large majority of retired motor vehicles currently flow directly into the scrap recycling process and the added incentive of a fee would increase the flow by some measurable amount.

The use of fines would also require the development of a regulatory enforcement activity which is not necessary with the use of the fee or incentive system. It is possible to couple the issuance of

fines and the associated surveillance activities into existing programs for identification and removal of abandoned vehicles. However, the use of fines and penalties has not had appreciable impacts upon reducing the number of abandoned vehicles and comparable experience could be expected for vehicles equipped with non-deployed air bags. Therefore, the level of perceptable benefits resulting from the use of fines would not justify the expense associated with the program.

6.4 Conclusions

The application of programs involving the utilization of fees or fines to encourage the flow of retired vehicles into the scrap cycle should be considered only as a last resort. Any form of subsidy or other side payment is undesirable because of the economic and administrative problems which are inherent in their use. However, any possible application of this type program should be conducted in conjunction with efforts to prevent abandonment of retired vehicles independently of whether or not these contain air bag restraint systems. This provision for joint or dual programs would provide economics in the staff, operation, and administration of the regulatory function.

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7. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This program was undertaken by ADL to assist NHTSA in assessing the risks associated with the use of air bag restraint systems during various stages of the passenger vehicle life cycle; identifying a series of programs which could be developed and implemented to reduce these risks and examining in detail several approaches to hardware modification which could be employed to reduce the risk associated with the handling and disposal of retired air bag inflator modules. A series of analyses were undertaken to examine the nature of the risks associated with air bag restraint, to propose and assess several amelioration programs, and identify and to evaluate in detail alternative feasible hardware oriented approaches which could be implemented to expedite the safe use and handling of retired air bag inflator modules.

The completion of a risk assessment analysis indicated that the primary hazards associated with air bag systems are manifested within the automobile dismantler/recycler and scrapyard operations. A countermeasure analysis was completed and the results demonstrate that the risks associated with air bags can be minimized by employing a series of countermeasure options during the pre-event stage of the recycling operations. The most effective countermeasure involves the application of physical, chemical or electrical stimuli to deploy the retired air bag early in the retirement program.

It was recognized that the efficient handling of retired air bag inflators requires that the number of abandoned motor vehicles be maintained at a minimum level. Therefore, several programs were examined to assess their feasibility for maximizing the number of retired motor vehicles which enter the salvage cycle. Only after the retired vehicle enters the scrap cycle can alternative procedures be examined to insure that the air bag is safely handled and deployed. Three proposals, including mandatory inspections, and bounty/incentives and fines/disincentives, were briefly examined to assess their feasibility for increasing the number of vehicles which enter the scrap

cycle. It appears that the mandatory inspection program provides one viable approach for minimizing the number of abandoned vehicles,

Once the retired air bag equipped vehicle enters the salvage cycle, there are several approaches which could be utilized to insure that the inflator module is safely deployed. Several hardware oriented approaches were identified as providing feasible designs which could be used to expedite the deployment of retired inflators. These individual options were evaluated according to several parameters including technical feasibility, cost, impact upon inadvertent deployments during normal use, accidental deployment during servicing and repair, time frame for implementation, cost for deployment devices and other considerations related to employee safety, special licensing, or other requirements for safe handling and storage of the deployment apparatus.

The results of this analysis indicate that the use of a 12-volt dc source to deploy the air bag is the only approach which is immediately available for appliation. It is also the least expensive and should not markedly effect the reliability of the air bag during normal use. The only disadvantage of this approach concerns the potential vulnerability of the air bag to vandals or other individuals with malicious intentions. It is not possible to predict the level of vandalism which might result from these type installations. Other more complicated and costly deployment procedures are based upon the use of piazoelectric igniters, electronic locks, and induction coils. These devices are all more costly, less reliable with respect to inadvertent deployments and require from 1 to 3 years for development. Other more sophisticated deployment procedures including the use of lasers, ultraviolet radiation, microwaves, and ultrasonics, provide possible long term approaches (3-5 years) to safe deployment of inflators.

This analysis represented a preliminary assessment for the identification of various programs which could be employed to assist in the safe handling and disposal of retired air bag inflator modules.

These alternatives should be examined in more detail to select a subset for further development including the assembly of necessary hardware components. Only then could the individual designs be rigorously evaluated to determine their effectiveness.

8. ACKNOWLEDGEMENTS

The following individuals were contacted during the completion of this study:

George Beiswinger, Talley Industries, Mesa, Arizona

William Boutwell, Aberjona Auto Parts, Woburn, Massachusetts

Alan Breed, Breed Inc., Fairfield, New Jersey

Herschel Cutler, Institute of Scrap Iron and Steel, Washington, D.C.

Clarence Ditlow III, Executive Director, Center for Auto Safety, Washington, D.C.

William Haddon, President, Insurance Institute for Highway Safety, Washington, D.C.

Murray Leonard, Manager of Igniter Products, Vernitron Piezoelectric Division, Bedford, Ohio

Leon Jones, Thiokol, Wasatch Division, Brigham City, Utah

David Lambert, Executive Director, Automotive Occupant Protective Association, McLean, Virginia

Russell McKinnan, Executive Vice President, Automobile Dismantlers and Recyclers of America, Washington, D.C.

H. Southworth, Division of Environmental Quality Engineering, Commonwealth of Massachusetts, 600 Washington St., Boston, MA

Hugh Richards, Thiokol, Wasatch Division, Brigham City, Utah

John Repp, Manager, Passenger Restraint Engineering, Ford Motor Company, Dearborn, Michigan

George Smith, General Motors Inc., Dearborn, Michigan

ACKNOWLEDGEMENTS (Contd)

Robert Smyth, Piezotechnology, Inc., Orlando, Florida

J. Sterner, U. S. Bureau of Mines, Salt Lake City, Utah

Ramie Thompson, Applied Physics Laboratory, Franklin Research Institute, Philadelphia, Pennsylvania

Richard Wolanski, Technical Director, Huron Valley Steel, Belleville, Michigan

Jay Zimmern, Proler Corporation